MYCOLOGICAL SERIES—BULLETIN No. II

DEPARTMENT OF AGRICULTURE
MYSORE STATE

DISEASES OF THE ARECA PALM

I.

KOLEROGA

BY

LESLIE C. COLEMAN, M.A., PH.D.

Mycologist and Entomologist to the Government of Mysore

BANGALORE:
PRINTED AT THE GOVERNMENT PRESS
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FOREWORD.

THE presentation of the results of the investigations on the disease known as "Koleroga" of the Areca Palm has been attended by considerable difficulty. In the first place, it has been necessary to give a clear and popular description of the nature of the disease and of the experiments carried out in the combating of it. Such an account of any scientific investigation must, of necessity, be imperfect. In the second place, in order to do justice to the subject itself and to the work that has been done upon it, a more technical and scientific statement of the investigations carried out and the results obtained is also necessary. The publishing of these two sides of the subject in two different reports would necessitate a great deal of duplication both as to text and as to illustrations. In order to avoid this it has been thought advisable to publish the two aspects of the subject as two separate parts of the same bulletin. Part I therefore contains a popular description of the disease, of the area it covers, the conditions favouring its appearance and the experiments carried out in the field for the checking of its ravages. In Part II is to be found a technical description of the fungus causing the disease and a comparison of it with related fungi. An attempt has been made to avoid repetition as far as possible, but a certain amount of duplication was, in the nature of things, inevitable. In order to make the presentation as clear as possible, numerous illustrations have been added to the text, and

it is hoped that they will serve the purpose for which they were intended. All the lithographic plates, except the two coloured ones, as well as text-figures, have been prepared by M. Ranganayakalu, Artist of the Department, who also made the paintings reproduced on the coloured plates. The photographs as well as all microscopic drawings were made by the author. My thanks are due to Mr. C. H. Yates, Superintendent of the Government Press, for the care he has taken in the printing of plates and text and for the advice he has given in the preparation of the former. A Canarese bulletin on the same subject is already in the press.

LESLIE C. COLEMAN.

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KOLEROGA OF THE ARECA PALM.

PART I.

KOLEROGA or Rot-disease of the Areca Palm is one of the most serious plant-diseases to be found in Southern India. Although it has been known for very many years and has more than once received the attention of the Mysore Government, from a scientific point of view it has remained almost uninvestigated. As is well-known, the disease in Mysore is restricted practically to the Western Ghat or malnad region of Shimoga and Kadur Districts. In this hilly area the narrow winding valleys are occupied by areca gardens, often of considerable extent, covering one hundred acres or more. More frequently the area of such a single tract is much smaller.

The disease is by no means restricted to Mysore. The accompanying map (Plate III) shows as accurately as the data I have been able to collect will allow, the distribution of the disease in South India. No record of it exists from any other part of India or from any of the other tropical countries where the areca palm is cultivated. As will be seen from the map, there are two infected areas apparently quite distinct and separate from each other. The larger one comprises parts of Mysore, South Canara and North Canara, while the smaller more southerly one occupies a small part of Southern Malabar and the neighbouring portion of Cochin. The extent of the area affected and the amount of damage done in Cochin, I have been unable to ascertain. The information with regard to Malabar and the Canaras has been kindly furnished to me by the Collectors of those districts, while I have also received valuable information with regard to the area infected in Southern Malabar from Mr. H. C. Sampson, Deputy Director of Agriculture, Madras, Southern Circle.

The disease appears to have been prevalent in the northern area for a much longer time than it has in the southern one. Enquiry made of the Mysore garden owners shows that the disease has been present here probably for very much more than a hundred years. On the other hand, the Collector of Malabar informs me that the disease appeared there for the first time about ten years ago. It appears fairly certain, therefore, that the disease has spread from the more northerly area to the more southerly one, but just how that spread has taken place is not known.

I have no accurate information as to the extent of damage done by this disease in parts outside Mysore, but what information is available points to decidedly less damage. This is probably due to the fact that the cultivation of areca is a very much more important industry in the affected districts of Mysore than in the other parts affected, rather than to any marked difference in the virulence of the disease.

If we consider more particularly the area infected by this disease in Mysore (see map Plate IV), we find that it comprises a tract in the extreme west of the State from the northern boundary about 80 miles southward. It is about 30 miles wide in its widest part. This tract occupies parts of Sorab, Sagar, Nagar and Tirthahalli Taluks of Shimoga District and Koppa Taluk of Kadur District. It coincides, on the whole, fairly closely with the great western areca-nut-growing district, for farther to the south the areca-nut is largely replaced by cardamoms and coffee. The distinctive feature of the whole area, outside of its being more or less mountainous, is the very heavy rainfall, the greater portion of which occurs during the months of June, July, August and September or the season of the south-west monsoon. Within the area marked, the annual rainfall varies approximately from 100 to 300 inches. It should be noted here, however, that there are still a few portions of the western areca-nut area which have, according to report, remained up to the present quite free from the disease although the rainfall is quite high. Kalasa, which in 1909 had a rainfall of 106 inches during the four months June-September, has no disease. This is, however, an exception and as such will be dwelt upon later.

PLATE I.

FIG. I.—Bunch of areca nuts attacked by *koleroga*. Many of the nuts on the left side of the bunch have already dropped. The brownish threads are the branches which bore the male flowers.

FIG. II.—Two areca nuts from a diseased bunch. The one to the left shows a fairly advanced stage of the disease. The one to the right is still quite healthy. About three-quarters natural size.

FIG. III.—Areca nut showing the first external signs of the disease. Towards the base of the nut are to be seen the water-soaked areas of deeper green which mark the place where the fungus will first break forth on to the surface. About three-quarters natural size.

Plate I.

I.

II.

III.

Chromolith. E. Laue, Berlin S.

As an isolated case, the disease has been found at Sakrepatna to the east of the Baba Budans, and it seems probable that the disease is to be found in the mountains themselves, but as yet no explorations have been made there. Finally, a doubtful case has been reported from Solur in Bangalore District, but absolute certainty was not established with regard to this being really Koleroga.

On the extreme eastern edge of the infected area is to be found a strip where the disease appears sporadically, depending upon the more or less favourable conditions in any one year. As an example might be taken Mandagadde, midway between Shimoga and Tirthahalli, where the disease did serious damage about five years ago, but which is reported to have remained quite free from the disease since that time. It appears quite certain, however, that this disease has extended during the last twenty-five or thirty years. Especially does this appear to be the case in Koppa Taluk. An intelligent garden owner living a few miles east of Koppa informed me that the disease had first made its appearance in his garden about twenty-five years ago. Now it is to be found still farther east. It seems unlikely that the disease will be able to extend much farther east, but a further extension towards the south in the area of heavy rainfall seems to me quite likely to occur.

It is hard to estimate the actual loss due to this disease in Mysore, but if we consider the annual crop in the affected area to be worth about 30 or 40 lakhs of rupees,* I think we may safely say that an annual loss of at least from 3 to 4 lakhs of rupees takes place. In bad years I have no doubt that the loss greatly exceeds this figure, and it probably rarely drops below it. In the case of individual gardens, the loss may run up to 75 per cent or even to practically a total loss of the crop. It is clear, therefore, that the loss is sufficiently great to warrant a determined effort to stamp out its cause.

* The following are the figures kindly furnished me by the Revenue Commissioner for the year 1908-09 for the five affected Taluks:—

Acerage under Areca cultivation	19,461 acres.
Approximate value of crop	Rs. 33,35,640.
Revenue derived	Rs. 2,16,384

THE CAUSE OF THE DISEASE.

The common opinion among the garden owners in the affected district has been that the disease is directly due to the heavy rains of the monsoon. This view is, of course, incorrect. The real cause is a parasitic fungus which lives in and on the areca-nuts, and which at times is able to pass over into the tree tops and kill them. The rains play an important part in the origin and spread of the disease each year, in that they give the conditions of moisture most favourable for the growth of the fungus.

Now, just what is a parasite? And what is a fungus? A parasite is a plant or animal which lives on or in another plant or animal and draws its nourishment from it, thus usually producing a diseased condition which may lead to death. A common example of a plant parasite is the Loranthus (Canarese, *Bandike*) which grows on the branches of the avenue trees throughout Mysore. A fungus is a plant of much simpler form than any of the common plants known to us. It consists chiefly of a system of colorless branching threads which spreads through the material on which it lives like a number of fine rootlets. Besides this, it is able to form fruiting-bodies and spores, which latter serve the same purpose as the seeds of higher plants. Some kinds of fungi form quite large and complex fruiting-bodies such as the toad-stools, the puff-balls and the shelf-fungi found on decaying logs, etc.; others have very small fruiting-bodies whose appearance and structure can be made out only with the aid of a microscope. Such are the blue and green moulds to be found on leather, bread, etc., during the monsoon.

The great majority of fungi are not parasites, that is, they live on dead animal and vegetable matter, not on living plants and animals. Many of them are, however, and most of the serious plant diseases are caused by them. In order to understand the disease Koleroga, it will be necessary to study the life-history of its cause carefully. It is only by so doing that we shall be able to combat it intelligently and with any likelihood of success.

Very soon after the monsoon breaks, usually about the beginning of July, the disease known as Koleroga of Supari makes its appearance in the malnad of Shimoga

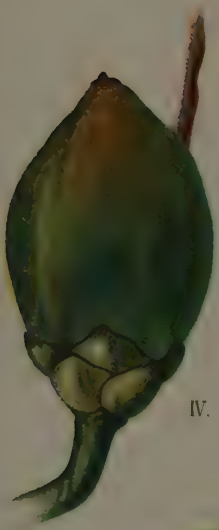
PLATE II.

FIG. IV.—Areca nut showing the first outbreak of the fungus on to the surface in the shape of whitish tufts at the base of the nut. About three-quarters natural size.

FIG. V.—A small portion of the surface of nut pictured in Fig. IV magnified to show the tufts of sporangia (fruiting bodies).

FIG. VI.—Areca nut showing an advanced stage of the disease where the fungus growth has covered practically the whole of the nut's surface. About three-quarters natural size.

Plate II.



IV.

VI.

V.

Chromolith. E. Laue, Berlin S.

and Kadur Districts. The first sign of the disease is given by the dropping of the nuts from attacked bunches. Such nuts, if examined, will be found to have lost more or less completely their clear green colour. Usually the surface will be found already to be partially covered with a soft whitish mass which can easily be scraped off with a knife or even with one's finger-nail. This is the so-called white Koleroga (see Plate I, Figs. I and II, and Plate II, Fig. VI). In some cases this whitish mass has not yet appeared at all on the surface. In this case, however, the presence of the disease can be made out from the fact that a part of the surface of the shell has become darker green in colour and has the appearance of being water-soaked (see Plate I). This discoloration is usually to be found first at the base of the nut. If such diseased nuts be kept for a day or so in a moist place, it will be found that the whitish substance gradually grows out from this water-soaked area and spreads from here over the whole surface of the nuts.

In order to understand just what this white substance is, we must examine it under the microscope. A little bit scraped off and put in a drop of water under the microscope will show that the mass is made up of innumerable whitish threads which are closely interwoven so as to form a sort of felt much like cotton lint or wool fibre that has been soaked in water. These threads are seen to branch and rebranch so that the whole mass seems to be a hopeless tangle.

This mass of threads makes up part of a living plant which is living in and on the areca-nut, sucking up nourishment from it and killing it so that it falls a prey to other organisms which make it rot. How do these whitish threads get on to the surface of the nut? If we examine a nut in the early stage of the disease we can readily answer this question. Such a nut will show on the surface here and there small whitish specks or patches (see Plate I, Figs. IV and V), and if we examine these even with a hand-lens, we shall find that these small white patches are made up of the same white threads we have mentioned above and that they are just breaking out from the inside of the nut. If we continue to watch such whitish patches for a day or so, we find that the threads which grow out from them intertwine themselves with

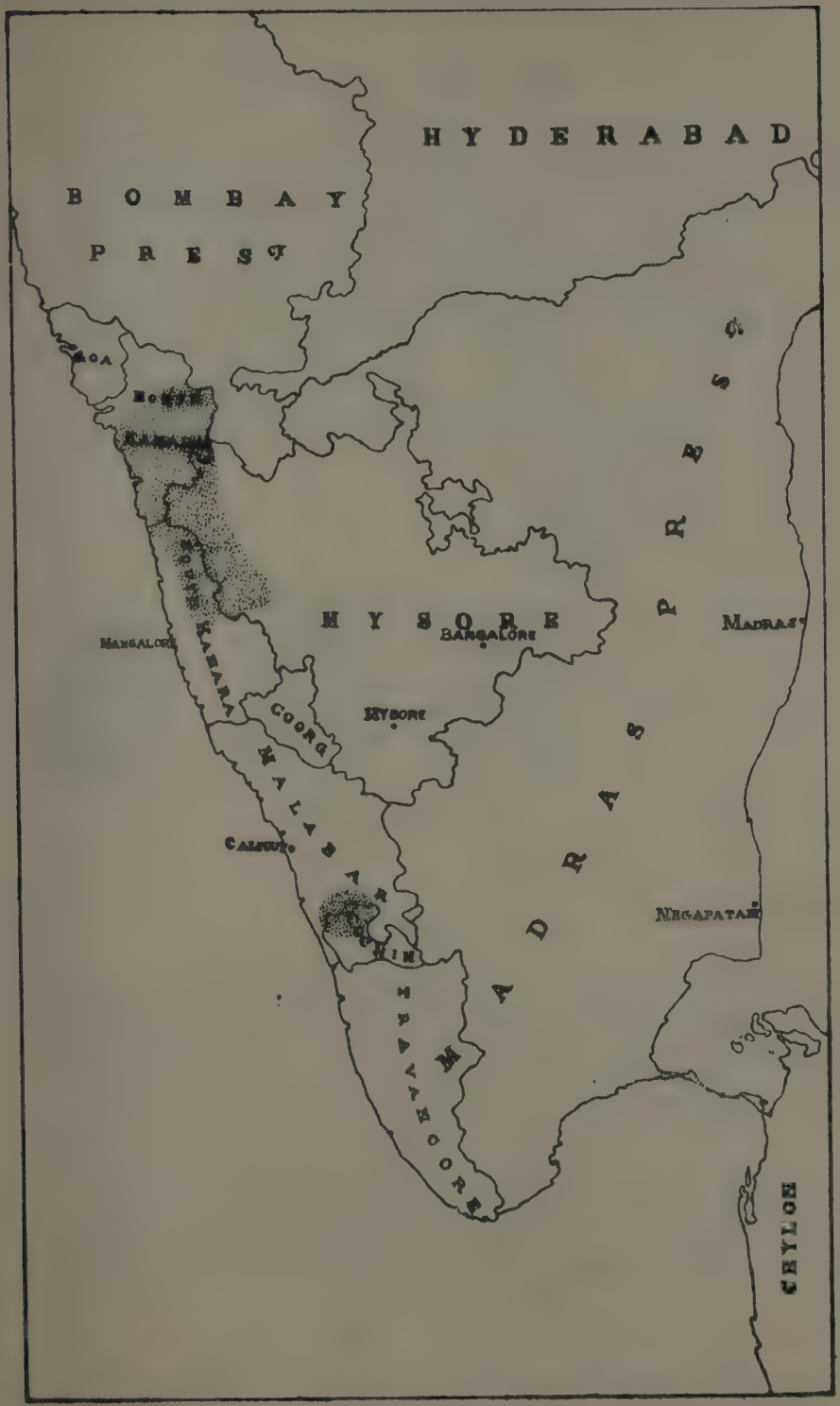
threads from other similar patches, so that finally the whole surface of the nut is covered by the tangled mass.

We see, then, that these threads which we find in a mass on the surface of the nut-shell have really grown out from inside. The question, then, naturally arises, how did they ever get inside in the first place? They cannot have been there from the beginning, for healthy nuts do not show any sign of such a growth on the surface.

In order to find out how the fungus got inside the diseased nut, we must study its life-history a little more fully. If we examine carefully the mass of tangled threads on the surface of a diseased nut, we shall find here and there, and often in large numbers among the threads, small, more or less egg-shaped bodies (see Plate II, Fig. v). These will be found, at least sometimes, attached by their broad ends to a branch of the threads just as fruit is attached by a small stalk to the tree that bears it. Often, however, they are found lying quite free, in which case they have simply broken loose from the small branch thread which bore them. This detachment takes place very readily. In Plate V, Fig. 3, which is from a photograph taken with the aid of a microscope, we see these egg-shaped bodies attached to the threads. In Fig. 2 of the same plate between *a-a*, we find the mass of threads with egg-shaped bodies showing up black in the mass. If we examine the small white patches on a nut showing the beginnings of the disease under a magnifying glass, we shall find quite frequently that these patches appear to be made up entirely of such egg-shaped bodies (Plate II, Fig. v). In other cases the fine threads are also to be seen, and in still other cases, only threads are to be found and no egg-shaped bodies. In any case where these egg-shaped bodies are found, they also are formed on a branch of the threads, and where they alone are to be seen, it simply means that the threads to which they are attached are down below them and so are hidden from view.

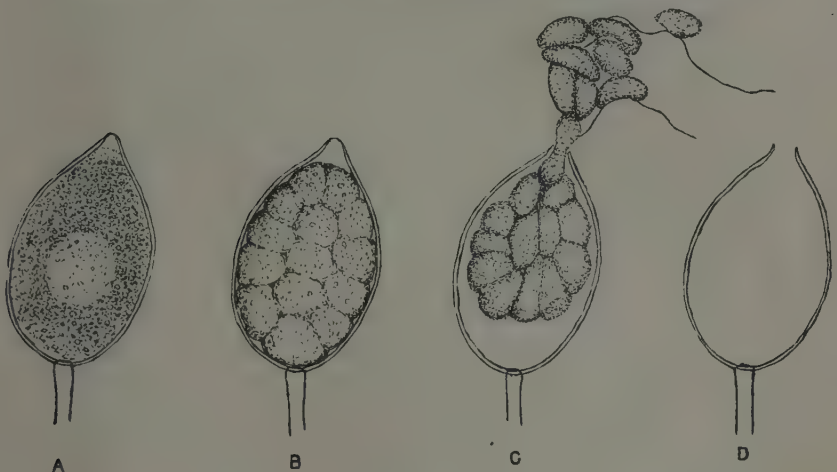
The course of growth and formation of these egg-shaped bodies or sporangia is shown in Plate XV, Fig. 1. The drawings here reproduced were made under the microscope at the intervals of time indicated beneath each drawing. As will be seen, the end of a thread simply enlarges until it has attained the full size of a sporangium when it becomes

Plate III


HYDERABAD
BOMBAY PRES.
GOA
MYSORE
BANGALORE
MADRAS
MADRAS PRES.
MANGALORE
SOUTH KANARA
COORG
MYSORE
CALICUT
MALABAR
COCHIN
TRAVANCORE
NEGAPATAM
CEYLON

separated off by a wall (at 12·40 in the figure). At the same time, one end becomes rather pointed, and here there is formed a clear space. At 1·35 a new branch had begun to grow out beneath the first sporangium, and this at 2·35 showed a new sporangium at its end about half formed. At 3·00 the second sporangium was practically formed, and at 4·00 the first sporangium emptied itself leaving the empty wall behind. The whole process from the beginning of the formation of the sporangium to its being emptied took about four hours.

These sporangia are very important organs. They are in reality the organs in which the seeds or spores are formed



TEXT-FIG. 1.

by means of which the fungus is able to reproduce itself. Each consists of a mass of granular substance surrounded by a clear thin wall. At the pointed end there is a clear spot where the granules do not extend right up to the wall. At this point also the wall is rather thinner than in other parts. If we watch this clear spot under the microscope for some time, we find that finally the body breaks open at this point and the granular contents begin to come out. As soon as the mass comes out, it breaks up into a number of small bodies, somewhat oval in shape, which at once begin to swim about in the drop of water in which they are placed. They do this by means of two long hair-like processes

which they whip through the water, and by means of which they are able to swim. The formation of these swimming bodies and their exit from the sporangium are illustrated in Text-Fig. 1. In A, the sporangium is fully formed, and shows the pointed end with the clear spot. In B, the contents have begun to divide up into individual spores or seeds. In C, the thin wall at the pointed end has burst, and the mass of spores are seen emerging in a clump. They separate immediately after emergence and swim off by means of the fine lashes which are shown on the two spores to the right. D shows the empty sporangium after all the spores have escaped.

These small swimming bodies are the seeds or the spores of the fungus, and each of the bodies which holds them (so-called sporangia) contains anywhere from ten to forty such spores. After they swim about in the drop of water for a period of time varying from twenty minutes to an hour or more, they come to rest, round themselves off and begin to sprout (see Plate XVI, Fig. 6). This they do by sending out one or more fine threads which grow to a considerable length. If, however, these threads do not find suitable nourishment, they soon die.

These spores are so minute that thousands of them could be contained in one rain drop, so that if a rain drop containing them falls on a healthy nut, they are able to sprout out there as already described. Here and there on the surface of the areca-nut are minute openings, the so-called breathing-pores. These are so small that they cannot be seen with the naked eye but must be looked for with a microscope. They are, however, quite large enough to allow the thread which has grown out from a spore to enter. The result is that, when a spore sprouts out, the thread in many cases finds its way through one of these breathing-pores into the interior of the nut. Such an infection of a nut is shown in Plate XVI, Fig. 7, where the germ tubes of three spores are shown passing down through the breathing-pore into the interior of the shell. One or two of the spores on the surface of the nut have not yet sprouted. When inside, they have an ample supply of food, for they are able to feed on the substance of the nut-shell and of the nut itself. This they do growing and branching till finally they have spread throughout the whole nut, much as the fine roots of a tree or bush spread

through the ground. On about the fourth or the fifth day after the fungus has entered into a healthy nut, the fine whitish threads begin to grow out on to the surface, first forming small whitish specks and then, through growth and branching, the felt work of fine threads already described. On these threads are formed again the egg-shaped fruit-bodies, and in these the spores or seeds, so that the fungus is ready to infect new and healthy nuts. Plate XV, Fig. 2, and Plate XII illustrate how the fungus breaks out on to the surface of the nut from the inside. In the case of some of the threads, the ends have begun already to enlarge to form sporangia. In the same Plate XII, Figs. 1 and 3, a surface view is given showing a number of sporangia in a cluster resting on the surface of the shell. The threads which bear them have broken out to the surface and have at once formed sporangia. Plate XIV, Figs. 1 4 show the threads of the fungus inside the tissues of the nut-shell.

It is now quite easy to see that if one nut on a bunch has become diseased, the other nuts are very likely to become infected. The heavy rains of the monsoon will wash thousands of these small spores from one nut on to another, so that infection takes place very readily. Where a diseased nut is in contact with a healthy one, infection may in all probability take place directly by some of the threads growing across on to the healthy nut and down through its breathing-pores into the interior.

But how does the disease spread from one bunch or from one tree to another? This at first seems a little more difficult to answer. If, however, we remember the weather conditions in an areca garden during the heavy monsoon rains, we shall not have much difficulty in understanding this also. The rain is usually accompanied by very heavy winds which drive drops through the air as a more or less fine spray. If we suppose some of these rain-drops to have fallen on to a diseased nut so that some of the small spores or seeds of the fungus have collected in them, the wind coming in gusts could easily drive such spore-laden drops on to a quite healthy bunch of nuts on a separate tree. Here they would begin growing, the threads would find their way down into the healthy nuts, and so the new bunch would become diseased.

If this is what actually happens, we should expect to

find the disease spreading in the direction in which the winds blow. That is, if a tree has the disease, it will spread the disease by means of spores carried in these raindrops to other trees on the side lying in the direction in which the wind is blowing. This is actually what we find takes place. In almost every case examined by me, I have found the disease spreading in the direction of the wind. This does not, of course, mean that no trees on the other side of the tree first attacked will take the disease. In fact, the disease usually does appear in several different places in a garden. This simply indicates that there are practically always a number of different places in a garden where the disease has been resting or sleeping from the previous monsoon all through the dry weather till the monsoon breaks again, and of this resting stage I shall speak below.

There is, however, another way in which these fungus spores might be carried from one tree to another. That is by means of small insects or even small birds. These flying about in a garden might alight on a diseased bunch or a diseased nut. When they fly away they would almost certainly carry some of these spores with them on their feet. If they should then fly to healthy bunches, they would probably deposit some of these spores there and so might lead to the spread of the disease. This, however, probably does not often occur. Insects and birds do not usually fly during the progress of a heavy rain, and it is only in the intervals between showers that they would be able to help in the spreading of the disease. It may be interesting, however, to note that near Sagar garden owners associated the appearance of the Koleroga with the appearance of a small fly. Whether these flies actually play any part in the spread of the disease must remain, at least for the present, merely a matter of conjecture.

We now know the cause of Koleroga and are able to understand how it spreads in a garden after it has once made its appearance. We have not yet considered just how it is able to exist from one year to another. The ordinary seeds or spores are very sensitive to drying out. In the laboratory it has been found that after a simple drying of five minutes they are dead, that is, they are not able to sprout if again brought into water. The fungus threads and the sporangia are also very sensitive

to drying out, so it is quite certain that this fungus is not able to live through the long dry season from October to June in the form we have already described. The usual view among the garden owners of the malnad is that the rain brings the disease. We have, however, seen that this disease is caused by a living organism, a kind of plant in fact. We know quite well that paddy is not brought by the rain, although it also begins to grow in this region soon after the monsoon breaks. We know in the case of paddy, as of all other plants, that the seeds must get into the ground in some way either by special planting or by chance, and that it is only when the seeds are in the ground, the paddy plants can grow up from them. Now, just in the same way, the Koleroga fungus cannot simply come down from the skies in the rain. Some of its spores must already be in the gardens where it appears and, as in the case of paddy, when the rain comes, these spores are able to sprout out and grow to form the fungus in and on the new nuts.

Where are these resting seeds or spores to be found? We should expect to find them where the disease had been the previous year, that is, in old diseased nuts on the ground or still hanging on the trees or in the dead tops of trees that have been killed by the disease. Such spores would, of course, be so very small that we could not see them with the naked eye, so we should have to search for them with a microscope. Even with this it might be difficult to find them, and, as a matter of fact, I have examined a very great many diseased nuts and also diseased tree tops from gardens and have not yet seen these resting seeds there. However, I have found them on nuts to which the disease has been given in the laboratory, so that I feel certain they are actually present in some of the diseased nuts at least.

These resting spores or seeds are quite different from the small swimming spores already described and pictured. They are larger, although still very small. They are so small in fact that it would take about a thousand of them placed side by side to reach the distance of an inch, and nearly one million of them could be placed on the space of one square inch.

These spores are fitted for resisting drought. They are round, or almost so, and the living substance is

enclosed by a comparatively very thick wall or coat which, of course, enables them to resist drying out very well indeed. Such resting spores are pictured in Plate XVIII, Figs. 1–3.

These bodies are formed in a rather peculiar way. The organs in which they arise resemble at first sporangia and are formed much as are the sporangia pictured on Plate XV, by the end of a thread swelling up until it is quite rounded off. Just beneath this swelling, another swelling or growth comes out of the same thread. The second body presses itself against the first and then sends out a fine tube which pierces the first body. Through this tube some of the substance of the second body passes over into the first. In fact, these two bodies are the organs of sex. The first body is the female organ, the second the male, and the act of fertilisation is represented by a part of the substance from the male organ passing over into the female organ. As soon as this occurs, the resting spore begins to be formed inside the female organ. The contents contract from the wall of the female organ and a fresh and thicker wall is gradually formed about it, so that we have a single spore or seed formed inside of it. Various stages in the formation of the resting spore are shown in Text-Fig. 2 and Plate XVII, Figs. 1–9.

As stated above, such a spore or seed is capable of sprouting out after a rest of several months. A large number of such resting seeds are probably formed every year in an infected garden. They remain there dormant until the following monsoon when, just like the paddy seeds, they sprout out and begin to grow. From them the healthy nuts are infected and so the disease is ready to proceed on its course again.

We have now a fairly complete picture of the whole life-history of the Koleroga fungus. We have seen how the fungus consists of a huge number of branching threads which are able to grow throughout the substance of the areca-nut and nut-shell and from there out on to the surface of the nut. We have found that on these surface threads small fruit-bodies or sporangia are formed, inside of which small spores are built. From here we have found the spores escape through a hole formed at one end and swim about in the water which, during the rains, rests on the surface of the nut. From here the

spores are carried by the wind and driving rain or by insects or birds on to fresh healthy nuts and even on to new trees. Here the spores come to rest and send out fine threads which enter through the breathing-pores on the surface of the nuts and so infect them. This, we found, is the way by means of which the disease spreads during the monsoon. We saw, however, that, besides these summer or monsoon spores, another kind was formed by the union of male and female organs and that these spores are able to resist drying out and so are able to live through the dry season much as paddy seeds do, so that they are ready to sprout out just as soon as the rains commence.

Up to the present, I have described the disease only as attacking the nuts and bunches. As a matter of fact, however, it does not always restrict itself to these parts. Occasionally it succeeds in making its way into the tissues of the tree top and in this case the tree is killed, death taking place within a comparatively few weeks. Luckily this does not happen often, so that the number of trees killed in one year in a garden is usually small. Many garden owners have placed the loss at about 1 per cent of the trees every year. In many gardens the loss in trees is, however, greater than this. Plate VI shows the top of an areca-palm dying from Koleroga attack. The bunches are quite dead and the leaves have begun to dry up and wither.

The fungus can get into the tree top in two ways. Either it can grow down the bunch stalk and from here into the stem or it can enter directly through the outer leaf sheaths into the tender growing point of the tree. Both these ways seem to be actually used, but the first way seems to be the usual one. Soon after the Koleroga fungus has entered, other organisms follow it, so that such a diseased top when examined is found to have become a rotten and evil-smelling mass. Plate VII shows a photograph of a tree top split in two in which infection has in all probability taken place through the bunch stalk. The bunch stalk is completely decayed and the stem at its point of origin appears diseased, whereas farther up towards the growing point it is apparently quite healthy. Plate VIII, on the other hand, shows the bunch stalk apparently quite healthy, while the growing point and the bases of the leaf-sheaths are badly rotten, indicating that the disease has entered at this point.

CONDITIONS INFLUENCING THE GROWTH AND SPREAD OF THE FUNGUS.

As the chief condition favouring the growth and spread of the Koleroga fungus must be considered the heavy rainfall of the monsoon and the constantly moist condition of the atmosphere consequent thereon. In this connection it may be noted that the garden owners both in Mysore and the Canaras appear to be universally of the opinion that the most favourable conditions for the spread of the disease exist when there is an alternation of rain and sunshine every few hours. The truth of this belief could be tested only by means of observations extending over a number of years, something which I have naturally not been able to make. However, it appears certain that there must be some real grounds for this view as it is so wide-spread. As will be shown later in the scientific part of this bulletin, the presence of an abundance of light appears to favour the emergence of the swimming spores from their sporangia, and as these swimming spores are the bodies by which the fungus is able to spread itself rapidly, we can readily understand that sunshine alternating with the rain might lead to a more rapid spread of the disease. If such sunshine were to last for any length of time, it would, on the contrary, check the disease by drying up the fungus on the surface of the nuts.

On the other hand, the belief is quite common that incessant and heavy rain tends to check the disease rather than to help its spread. On this point also I cannot speak from experience, but if it be true, it appears probable that it is due to two factors. Firstly, the light may not be sufficiently strong to bring out the swimming spores in great abundance, and, secondly, the heavy rains would tend to wash off any spores that might have been carried to healthy nuts, so that the chance of an infection of new nuts would be decidedly lessened. Observations will be made on these points as opportunity occurs, and it is hoped in the course of a few years to gain sufficient information to speak with moderate certainty on both these points.

Whether the height of a garden relative to the surrounding country and the consequent state of drainage

have much to do with the presence and spread of the disease, seems to me a matter of doubt. The opinion has been expressed by more than one that low-lying gardens with poor drainage are more liable to attack, but I have examined a number of gardens which were by no means low and where the drainage was good, and yet the disease was very prevalent indeed.

There is no doubt that gardens which have not been cultivated for a number of years are usually free or almost free from attack. There are exceptions and I can recall one garden inspected by me in the month of July, which was in a very bad state of cultivation, but which nevertheless was very badly attacked by Koleroga. In looking for a possible cause for this peculiar fact, it may be well to pass under review the differences between a so-called abandoned garden and one under good cultivation, and to consider which of the differences might have an effect upon the spread of the disease.

In an abandoned garden the trees are usually few in number and far apart, and the bunches are few and small in size. The ground is usually fairly covered with grass and of course there is no sign of manure of any kind. The drainage ditches have usually become almost or quite obliterated. On the other hand, in a well-cultivated garden, the trees are numerous and close together (400 bearing trees per acre is a common number), the bunches are usually large and numerous, the ground has been dug, drainage channels have been opened, and about the trees is to be found manure in the shape of leaf-mould and cattle-dung mixed, covered with twigs and branches. In addition, every five or six years the earth about the trees is replaced, fresh earth being brought in from the outside.

Of the factors which might have an effect on the spread of the disease, the first is the closeness of the trees together. The closer together the trees are, the less chance there will be for a rapid drying out in case of sunshine. The fungus will therefore have more favourable conditions for its growth than it would in an abandoned garden with the trees far apart. Closeness of the trees together would also allow for a much more ready spread of the disease, should it appear in a garden, and furthermore a loss from the disease is much more likely to be noticed in a thickly-planted cultivated garden than in

an abandoned one, where the crop in any case is often hardly worth the harvesting.

Turning to the conditions on the ground, it appeared to me possible that the presence of leaf-mould and manure in the garden might have something to do with the presence of the disease. It seemed just possible that the fungus might be able to grow in the leaf-mould and so remain alive in it from one year to another in the resting stage. It has been observed almost universally that where trees have been blown over in the monsoon in an infected garden and the bunches have come to be close to or touching the ground, such bunches are found to be attacked by Koleroga. This also appeared to point in the same direction. As will be detailed later on in the scientific part of the bulletin, it has been attempted to grow the fungus on the leaf-mould and soil taken from a cultivated garden where the disease was prevalent, but with very poor success indeed. So I feel myself reluctantly forced to give up the soil-and-leaf-mould theory for the present at least. Experiments are, however, still in progress to see just how long the fungus can remain alive in the soil. In any case, it appears to me now very difficult to believe that cultivation and manuring directly favour the growth of the fungus. The whole question will form the subject of further investigation throughout the coming rainy season.

Lastly, there is a belief fairly prevalent in the malnad that those gardens in which the nuts ripen early suffer more than those where the harvest is later. We find as we go southward in the western malnad region a more or less gradual change in the time of harvest from October-December to January-February and even to March. In certain districts in the south such as about Kalasa, the disease appears to be entirely absent. The garden owners in that region consider their tree to be a distinct variety of areca, but I have as yet had no opportunity of studying the question. In any case, it appears to me fairly certain that if the nuts in this region are really more resistant to the disease than those farther north, it is not because they ripen later but because of some other quality inherent in them. Even at Kalasa, where the nuts ripen so late as February, the chief flowering season falls in June and infection experiments have shown that

the flowers and young nuts are quite susceptible to infection. According to this, therefore, unless we have to do with a distinct and disease-resisting variety of the palm or unless in some unknown way the physical conditions are unsuitable for the spread of the disease, it seems difficult to explain the absence of the disease in these parts, except on the ground that it has not yet succeeded in spreading so far.

As to the belief in infected districts, that it is the older nuts which are most affected, I believe this is a mistake due to the fact that the more nearly ripe a bunch is when attacked, the more serious is considered the loss. A loss to older and more fully developed bunches would be much more keenly felt than would a loss to younger bunches. The account of the losses kept for various different harvests in the gardens experimented upon shows very little difference between losses found in the earlier harvests and those in the later, which would indicate that the supposed greater susceptibility of older nuts most probably does not exist.

COMBATIVE MEASURES.

The description of the disease already given was necessary in order to make clear to us the methods best suited for combating it. It is clear that if the drought-resisting spores remain in the garden from one year to another we should do all we can to remove them before the next monsoon breaks. As already pointed out, they must be present in those parts which were diseased the previous year. In order, therefore, to clear the garden as far as possible of these drought-resisting spores, we must remove all the diseased nuts and bunches on the ground or still hanging on the trees. In addition, we must remove all trees that have been killed as the tops of such trees are quite likely to harbour the spores. All these diseased parts, nuts, bunches, and diseased tops, should be carefully collected and burned. As the disease never spreads far down into the trunk of the trees, it is necessary to burn only the tops of diseased trees. The stems may be safely used for the many purposes for which they are now utilised. This destruction of diseased nuts, etc., is not carried out to any extent at present. Diseased nuts are

left where they fall on the ground and old diseased bunches are left hanging on the trees. Dead trees are also left until they are thoroughly dried, which means frequently more than a year. It would require very little additional labour and trouble to clean up the gardens every year especially if it were done, as it should be, at the time of harvest. A careful removal and burning of all parts is thus the very first thing to be done in the way of combating Koleroga. The carrying out of this policy consistently year after year is bound to have an effect in reducing the disease.

But this is not enough. We know that no matter how carefully paddy be harvested from a plot where it has been growing, some grains remain behind and that these will grow up the following year even though no paddy be planted. Just the same with the Koleroga fungus: no matter how carefully we may remove diseased parts, it is practically certain that some of the spores will be left behind and these will be ready the following year to sprout out and start the disease going again. Some one may say, What is the use of all the cleaning up and all the burning of diseased parts if we cannot get entirely rid of the disease ? While by carefully removing diseased parts we cannot get entirely rid of the disease, we can make the chances of its spread very much smaller, for the smaller the number of fungus spores left in a garden, the less the likelihood of their infecting large numbers of trees the following year. We can, in fact, reduce the chances of extensive damage by this means, but we must not expect thereby to get rid of the disease altogether.

From these facts it will be seen that we shall have to supplement this method by some other if we wish to get rid of the disease or at least to reduce the damage it does to as low a point as possible. We must, in fact, seek for some direct method to combat the disease or, if possible, to prevent its appearance in the garden during the monsoon itself.

As known to all, one such method is at present in use almost universally throughout the infected areas of the malnad. It consists of tying coverings made of the basal sheaths of the areca-palm leaves over the bunches to keep the rain off them. The idea in so doing came from the belief that the disease is brought by the rain. As we have

seen, this is not really the case. However, we have seen that water on the nuts is necessary for the spread of the disease and also that the disease is spread most extensively by means of rain drops carried by the wind, so anything which will tend to keep off the rain will also tend to keep off the Koleroga fungus.

These coverings are made in two different ways in different parts of the malnad. In every case each covering is made of two basal sheaths sewed together. In Sagar Taluk they are made as follows:—One sheath is split lengthwise and one-half is sewed on to each side of another whole sheath. This covering is then tied around the bunch much like a sleeve. The tying is done by means of bands also obtained from leaf-sheaths. Such a covering in place on a bunch is shown in Text-Fig. 2. The other type of covering is rather different and is to be found in use through Nagar, Tirthahalli and Koppa Taluks. In this type, as shown in Text-Fig. 3, one sheath is fastened crosswise at the end of the other in such a way as to form a sort of cap which fits over the bunch. Still another kind of covering has been used, but only in an experimental way. It consists of a piece of tin made in the shape of a sort of scoop which is inverted over the bunch.

Of these types, undoubtedly the best and most efficient is the one in use in Tirthahalli, Nagar and Koppa Taluks. It fits the bunch better and is less likely to become dislodged by the heavy winds. However, it does not allow for an adequate protection to the sides of the bunches, especially if they are at all large. The type used in Sagar Taluk, on the other hand, protects the sides of the bunches quite well. It does not, however, protect the top especially if the bunch stands up well on the tree. In such a case the open end of the sleeve is directed upward instead of downward or outward and the whole covering serves as a funnel to catch the rain rather than as a protection to keep it off. As this type does not adapt itself to the shape of the bunch so well as the other, it is more easily dislodged by the wind. It also tends to break open along the lines on each side where the parts are sewed together.

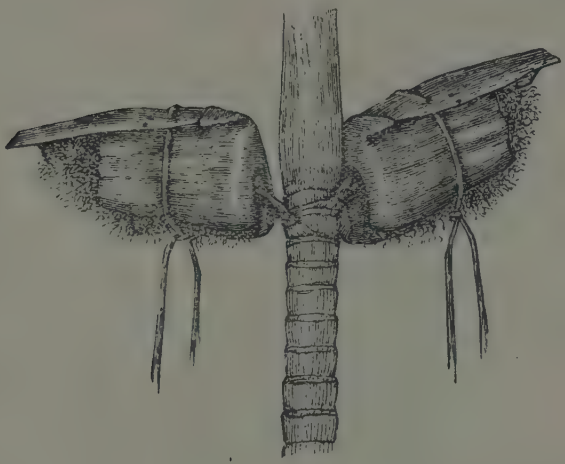
As to the third type or the tin covering, it has, practically speaking, never been used. It was in use to a very slight extent about Sringeri, but garden owners with

whom I spoke told me that it was not a success. They said that in the heavy winds it tended to cut and injure the bunches, while on hot, sunny days the tin became so hot that the nuts were practically baked beneath it. The fact that it is quite inflexible would indicate also that it would not fit well on to the bunches and would easily become dislodged. In fact the only thing in its favour is its greater indestructibility. It is, however, not at all likely to prove more satisfactory than the coverings already in use, while its greater cost practically prohibits its use.

TEXT-FIG. 2.

As already indicated, these coverings are by no means perfect protections against the disease. The heavy winds of the latter part of July and the consequent striking of one tree against another are certain to crack or dislodge a goodly number of them, in which case they are likely to do harm rather than good, as they tend to keep the rain water in about the bunch and in case fungus spores drop on to such a bunch, conditions as nearly perfect as possible are provided for their growth. Other coverings rot on the bunches and in this case also they are worse than useless.

Another point in their use has to be considered. Two leaf-sheaths are required to form a covering for each bunch. Now under each leaf-sheath which falls from the tree is formed a bunch of nuts so that should all these bunches develop there would be just the same number of leaf-sheaths available as bunches. As a matter of fact, not all the bunches do develop. On the other hand, not all the leaf-sheaths that drop are saved. Many of them rot in the garden during the monsoon and others split in falling from the tree. Besides, the sheaths have many uses other than that of forming coverings for the bunches.



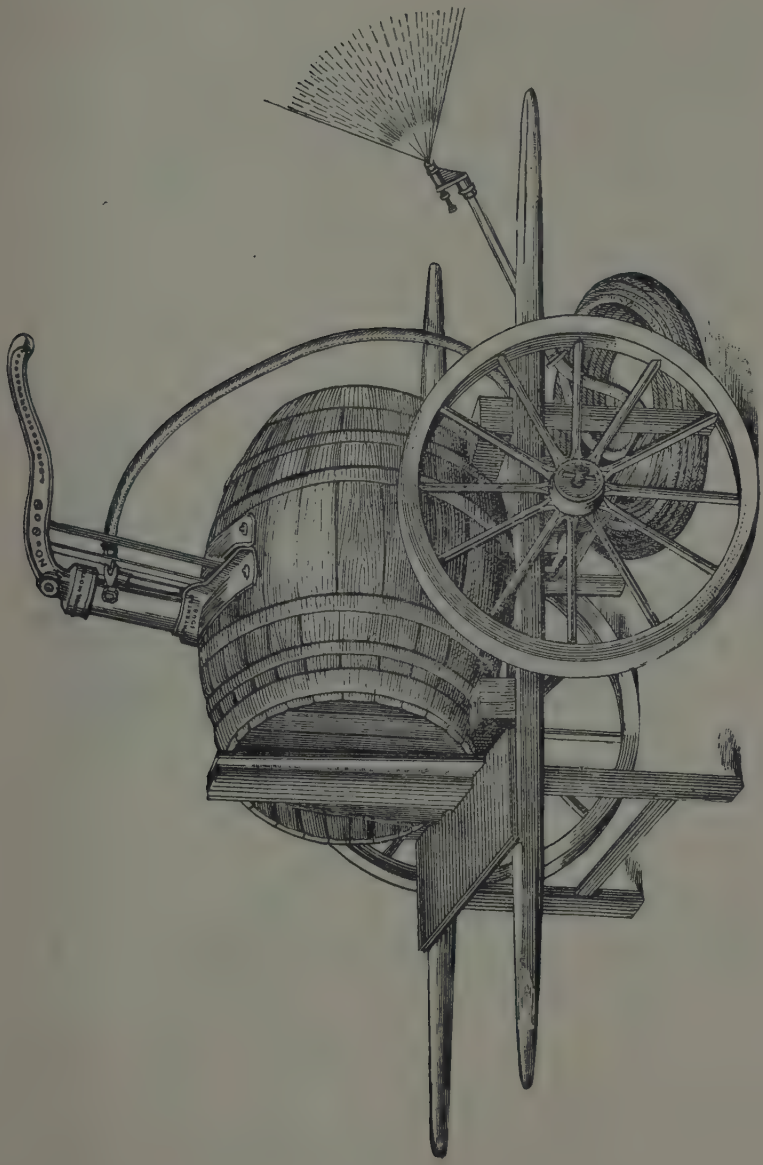
TEXT-FIG. 3.

We see, then, that it would be impossible to tie coverings on all the bunches in a garden even if all the leaf-sheaths that fall should be used for that purpose. As we shall see presently, however, no thorough combative work can be done and no hope of stamping out the disease can be held out unless the measure be carried out thoroughly and practically all the bunches in a garden are tied. We thus see that it will be impossible to carry out the tying of *kottes* or covers as thoroughly as it should be done. I have as yet seen no garden the whole of which had been treated in this way.

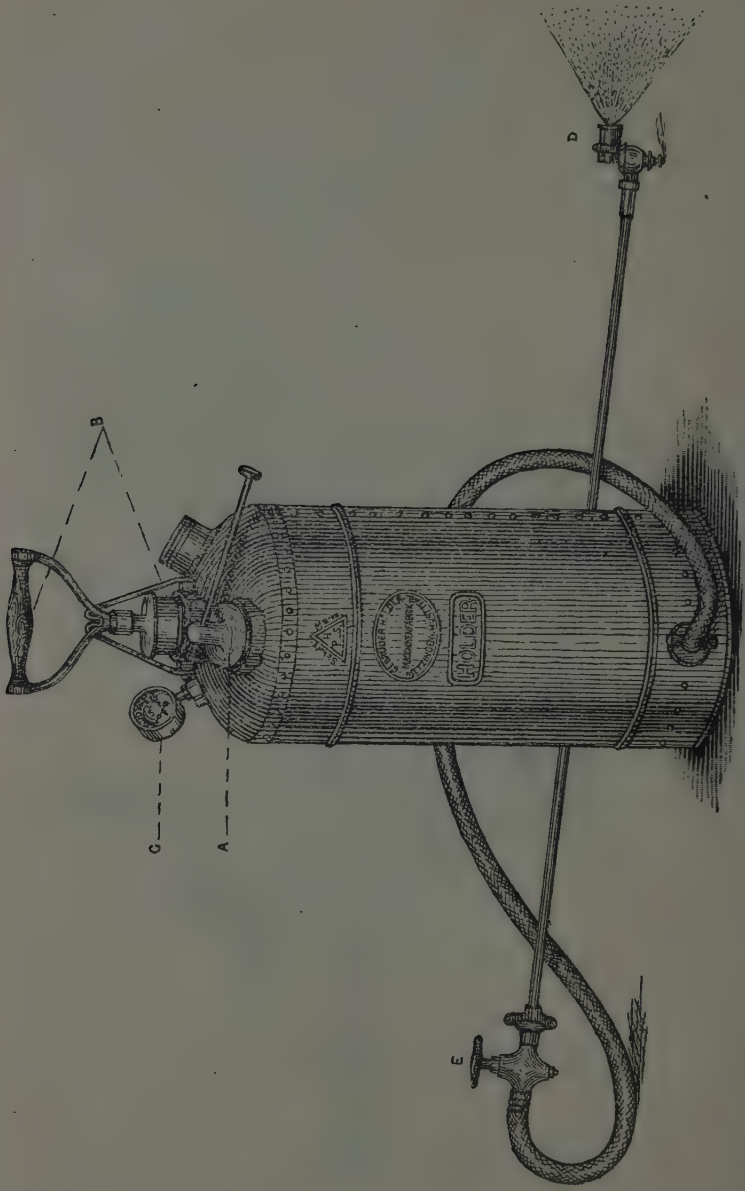
As to the time when the coverings should be tied, it seems quite clear that as the fungus is spread by wind

and rain, the earlier in the monsoon the coverings are tied, the more thorough will be the protection from the disease. In fact, this work should be done before the monsoon has really begun, to make quite sure that no outbreak has taken place already. The common objections to early *kotte*-tying are threefold—firstly, the bunches are small and therefore either they will be hindered in their growth by the coverings or these coverings in their turn will be burst by the growing bunches; secondly, if the coverings are tied on before the heavy winds of the latter part of July, they will, to a large extent, be knocked off and broken by those winds; and thirdly, it is most difficult to get sufficient labour to do the tying earlier than the middle or end of July.

All of these objections have a certain amount of weight and it was on account of them as well as on account of the general imperfections of this method of combating the disease that extensive experiments have been carried out to test what is really the best method of keeping it under control. It was thought that perhaps a more effectual method would be found in coating the nuts and bunches with a substance which would prevent the growth of the fungus spores should they happen to alight there. Such a substance is the so-called "Bordeaux mixture," the name of which comes from Bordeaux, the part of France in which the substance was first used to combat a disease of the grape vine caused by a fungus. This material is, as the name implies, a mixture. Its ingredients are bluestone and lime in certain proportions in water. When complete, it has a bright blue color, which can be readily seen on the nuts and bunches even from the ground. The directions for making this mixture will be given later. It is usually applied by means of instrument called a sprayer. The sprayer first used in the experiments (see Text Fig. 4) consisted of a barrel mounted on wheels with a force pump and a long line of cotton tubing which reached to the tops of trees. At the end, the opening or nozzle was so arranged that the fluid came out in a fine mist-like spray and so could be spread very evenly all over the bunches. In addition to the copper sulphate and lime, a small amount of resin and soda boiled till it was clear was also added. This was to give the mixture greater sticking



TEXT-FIG. 4.



TEXT-FIG. 5.

power, so that it would not be so easily washed off by the rain.

The barrel-sprayer used proved fairly effective, but most unhandy as it was very heavy and difficult to move about in the gardens where deep drains run between the rows. It was decided, therefore, to get a small sprayer which could be carried up the tree by the climber. In this case it was necessary to have one in which the fluid could be expelled by compressed air pumped into the sprayer before it was taken up. In my work in Europe I had used such a sprayer and decided therefore to get two out for trial. They arrived late but still were tried and proved very satisfactory. They hold about one gallon of fluid and are so light that climbers find no difficulty in carrying them. The spray can be sent out in a very fine mist or can be regulated to a coarser mist. Still another end piece allows a jet of the fluid to be sent out and by means of this the bunches on very high trees can be reached even such as on account of their height cannot be reached for tying coverings. Text-Fig. 5 shows one of these sprayers. It consists of an air-tight vessel made of copper. At A is the small cover which is screwed into the opening through which the mixture is poured into the vessel. Into the vessel is poured a gallon of fluid which fills it about two-thirds full. The cover is then screwed on tight. Air is pumped in by means of the pump B until the pointer on the gauge C has travelled over to a red mark on the face, which indicates that sufficient air has been forced in. In order to set the sprayer going, the stop-cock E is turned and the compressed air in the vessel forces the fluid out at the opening of the end piece or nozzle D. This is so constructed that the fluid is forced out as a fine mist. The cap of the end piece D can be replaced by others which give different kinds of spray as indicated above. Text-Fig. 6 shows the small sprayer in actual use on a tree in one of the gardens.

EXPERIMENTS IN THE PREVENTION OF KOLEROGA.

Two preliminary experiments in spraying were made during the monsoon of 1908. In each of two gardens, one at Hale Ikkeri near Sagar and one at Bellenne near

Talaguppe, about twenty trees were sprayed with a strong solution of Bordeaux mixture to which had been added an adhesive. In one of the two gardens the disease had already broken out, and spraying was done on the three or

TEXT-FIG. 6.

four already infected trees as well as on those in their immediate neighbourhood. The results showed a perfect success. The disease was checked or stopped on the trees already infected and an officer of this Department on

inspecting the gardens in September reported that the disease had not appeared at all on the treated trees, although the spraying had been done at the beginning of June and the disease had been prevalent in both gardens.

It was the success of this preliminary experiment which led me to try experiments on a more extended scale during the rainy season of 1909. Arrangements were made for the leasing of portions of gardens in all of the four badly affected taluks, *viz.*, Sagar, Nagar, Tirthahalli and Koppa, with the view of testing the following points :—

1. The relative efficacy of spraying and tying of *kottes*.

2. The relative efficacy of early treatment before the beginning of the monsoon and late treatment during a break in the monsoon.

3. The most suitable strength of spray.

The gardens selected with their areas were as follows :—

Sagar Taluk—
Patel Subbarayappa's garden, Hale Ikkeri near Sagar; extent one acre.
Subbiah's garden, Bellenne near Talaguppe; extent 35 guntas.
Nagar Taluk—
Garden at Basti near Sampekatte.
Matt garden at Sampekatte.
Tirthahalli Taluk—
Garden of K. Venkata Rao at Karodi near Tirthahalli; extent 20 guntas.
Garden of Venkatramaniah at Hosur near Agumbe; extent 28 guntas.
Koppa Taluk, Yedahalli Sub-Taluk—
Garden of K. Venkata Rao at Seethoor near Koppa; extent 20 guntas.

The work on the gardens situated in Nagar Taluk had to be abandoned, as the very early break of the monsoon with the consequent swelling of the intervening rivers made the road to them impassable. In fact, the early beginning of the monsoon was a serious hindrance to the whole work and prevented it from being as successful as it would otherwise have been. The intention was to do all spraying before the rains commenced. The spraying was not begun till the 3rd of June and that was

actually the date when the monsoon broke instead of a week later as is usual. The small sprayers which had been ordered in the previous December had not arrived owing to an almost unpardonable negligence on the part of the manufacturers, and this was the reason why the spraying was put off to so late a date. As it was, almost all the spraying had to be done with the cumbersome barrel-sprayer mounted on wheels, which was used the previous season. This is by no means an inefficient sprayer but is very unhandy, for it is so heavy that when filled with solution it can be moved about the gardens with their deep drainage ditches only with the greatest difficulty. The 60 or 70 feet of pipe necessary to reach to the tops of the higher trees is also a rather awkward thing for a climber to handle. The small sprayers arrived and were first used in the Seethoor garden. It could at once be seen that they were an infinite improvement and that with them work could be done very much faster.

In discussing the results of the spraying experiments it is necessary to make some introductory remarks. In all the gardens but one (that at Seethoor) at the same time as the spraying was being done on certain trees others had *kottes* or covers tied on their bunches. Thus the two treatments were done under exactly the same conditions. In estimating the losses arising, it is necessary to take into account one point which might easily escape our notice. The majority of bunches in every garden lose during the season, especially during the month of July when the winds are particularly high, a number of nuts from physical causes. Such losses are due largely to the striking of bunches together or to the direct action of wind on the bunches. These natural losses have nothing to do with the disease and, in fact, would still exist were the disease to be stamped out altogether. It is clear that it would be quite unfair to charge such a loss to Koleroga in cases where Koleroga has destroyed a number less than or even equal to the average loss from natural causes. In an attempt to obtain results as exact as possible, a count was made of the losses of nuts on perfectly healthy bunches and the average loss per bunch was thus struck. The number of bunches on which the natural loss was counted was never less than fifty or more than a hundred. As will be seen in the account of

the individual experiments, an astonishing difference was to be noted in the natural losses in the different gardens, varying from sixty nuts per bunch in one garden to five nuts per bunch in another. This great difference is probably to be accounted for through local differences in the force of the wind, differences in the thickness of trees together as well as in the size of the bunches, a greater loss naturally taking place on a large bunch.

In comparing the effects of spraying and the tying of *kottes* one cannot hope to get more than relative and approximate figures. It seems quite possible that the act of tying a covering over a bunch of green nuts four or five months before the harvest might have a considerable effect on their development, for under natural conditions they are much more exposed to both light and air than they are under a cover. The pressure of a closely tied cover on growing nuts might also be thought to have some effect on their development.

On the other hand, it might be possible that the solution put on would either stunt the growth of the nuts or injure them in some other way. The extensive experiments that have been carried out on the potato, the grape vine, etc., however, make this very improbable. According to some experiments the spraying has, in fact, a directly beneficial effect, leaving the question of disease out of consideration altogether. The only noteworthy injuries to fruits or plants I am aware of are the spots produced on the fruits of certain varieties of apples, and the burning of the fruit and leaves of the peach, etc. At the beginning it may be said that in all the thousands of nuts sprayed this year not the slightest sign of any such injury was to be seen, so we are safe in saying that the Bordeaux mixture has no injurious effect upon the nuts.

Whether, on the one hand, the covers do stunt the growth of the nuts and whether on the other the Bordeaux mixture may have a stimulating and beneficial action as has been made probable for it on potatoes is difficult to answer, for the differences which might exist in the normal crop in two parts of the same garden might be so great as entirely to hide any differences produced by different methods of treatment.

The best way to compare the results of the two methods of treatment seems, therefore, to be the giving of—

1. The actual number of bunches affected.
2. The number seriously affected.
3. The actual loss of nuts reckoned in bunches.

This last is to be obtained by finding the average number of nuts in a bunch in the garden under consideration and by dividing this into the number of nuts lost through Koleroga. As the number of trees sprayed and those tied with *kottes* depended upon circumstances in the gardens and were never exactly the same, in order to compare results the losses must be expressed in percentages.

It should be expressly noted that, as soon as the gardens were leased several months before the break of the monsoon, care was taken to put all the gardens in as sanitary a condition as possible. All the old dead bunches left hanging on the trees were carefully removed and all decayed bunches and nuts lying on the ground were picked up. From the fact that this work was found necessary in every one of the gardens and from my observations throughout the whole affected tract it seems fairly certain that this first essential measure in the combating of the disease is never carried out by the garden owners.

EXPERIMENTS IN PATEL'S GARDEN, HALE IKKERI.

This garden was divided up into five longitudinal sections in the following order:—

For early spraying	...	Six rows
For late tying of *kottes*	...	Four rows
Untreated	...	Four rows
For late spraying	...	Four rows
For early tying of *kottes*	...	Six rows

Here, as elsewhere, that portion of the garden which had been most badly affected the previous year was sprayed with the idea of making the test for spraying as hard as possible. In this case the part affected the most the previous year was that set apart for early spraying.

The first spraying was done on the 8th of June, the *kotte*-tying being done on the 6th. The weather was very unfavourable for spraying there being frequent heavy downpours interspersed with dry spells about equally

divided. In the evening there was a dry spell of about two hours after the spraying was finished. The late spraying and *kotte*-tying was done on the 18th of July. As, however, no disease had as yet appeared in the garden no fair test could be made as to the efficacy of early and late treatment. As already pointed out, the great danger in delaying combative measures till late lies in the fact that the disease is likely to appear and have a chance to spread before anything can be done to check it. The conditions under which the late spraying was done were perhaps slightly better than those for the first spraying. Most of the time there was sunshine with a very little rain. About twenty minutes after the spraying was finished there was a heavy shower which lasted about half an hour.

A count of a hundred healthy bunches in this garden gave an average of thirty-nine nuts knocked off by the wind or dropped from other natural causes, and an average of 240 nuts harvested from each healthy bunch. The harvest results are given in the following table:—

Method of treatment	Bunches harvested	Bunches attacked	Percentage attacked
Early spray ...	154	25	16
Late spray ...	121	20	16
Early *kotte* ...	113	32	28
Late *kotte* ...	71	17	24
Untreated ...	240	150	62

From this it can be clearly seen that although the spraying was done under unfavourable conditions the results show a decided advantage over those obtained by *kotte*-tying in the matter of bunches attacked. If we now consider only the bunches badly attacked or those which have had a loss of seventy-five nuts or over, we get similar results:—

Method of treatment	Bunches which have lost 75 nuts (approximately ¼ bunch) or more	Percentage badly attacked
Early spray	10	7
Late spray	6	5
Early *kotte*	14	12
Late *kotte*	9	12·5
Untreated	85	35·4

The total loss in bunches can be ascertained by dividing the total amount of nuts diseased by 240 or the

average number of nuts per bunch. If we do this we get the results given in the following table:—

Method of treatment	Bunches harvested	Bunches lost	Percentage of loss
Early spray ...	154	11	7·2
Late spray ...	121	7·8	6·4
Early *kotte* ...	113	12	10·6
Late *kotte* ...	71	7·5	10·4
Untreated ...	240	97·5	40·6

These last results are similar to the ones already given and show clearly that spraying, although done only once and conducted under unfavourable conditions, has given results decidedly better than the tying of *kottes*. On the other hand it is equally clear that the tying of *kottes* has been a decided protection for on the area untreated the loss has been much heavier. As will be pointed out later, it does not, however, reveal the great weakness of the *kotte*-tying, *viz.*, its inability to cope with the disease under favourable conditions of spread when it has once gained a foothold in a garden. None of the actual experiments conducted show this, as in no case had the disease appeared in any part of the garden before the treatment was given.

Another point upon which the experiment does not throw light is the relative value of early and late treatment. The differences noted in the above tables are too slight to allow us to draw any conclusions, and would on the whole appear to favour late treatment. A very little consideration will show us that the chances of any preventive treatment's being effective will be much greater if such treatment can be applied just before the appearance of the disease. By this means the full strength of the treatment will then be available to prevent the spread of the disease. If we could foresee definitely when Koleroga is to appear, spraying a few days before such time would probably be most effective, and the same applies to the tying of *kottes*. However, this is just the thing that we cannot foresee with certainty. Case after case has come to my attention where garden owners, thinking that the disease would not appear, have delayed making any preparation with the result that the disease has come upon them unawares and they have lost the greater part of their crop. Thus, although the results this year do not

show any appreciable advantage of early treatment over late treatment, it cannot be too strongly emphasized that early treatment is by far the safer, and in the case of the tying of *kottes* the only treatment that can be at all recommended. In support of this I wish to point out again that the disease is present in the garden and has gained a foothold invariably before it is to be noticed. As already pointed out, a period of from four to five days elapses between the infection of nuts and the appearance of the fungus on the surface.

EXPERIMENTS IN THE BELLENNE GARDEN.

Here also the garden was divided up into separate portions for early and late treatment both spraying and *kotte*-tying. Only a few (some twenty) trees were left untreated and upon them the crop was almost an entire failure.

The division was made as follows :—

For early spraying	...	... Six rows
For late *kotte*-tying	...	... Six rows
For late spraying	...	... Six rows
For early *kotte*-tying	...	... Six rows

In the early spraying the plot was divided into two parts of three rows each, one portion being sprayed with strong solution, the other with weak. Unfortunately a mistake was made in the adhesive used in this early spraying, 1 lb. of resin being used instead of two. The results in consequence were unsatisfactory and give the only case in all the gardens experimented upon where spraying was less efficient than the tying of *kottes*. In the late spraying, only the strong solution was used and the adhesive was properly made. In this case, as will be seen, the results were quite satisfactory. The owner of this garden did not live up to his agreement and in fact in every way hindered the work of harvesting. The results given are for the second and third harvests only, as though the owner had agreed to notify me when the first harvest was to take place, he did not do so ; so no record could be kept of it. In this garden the number of nuts knocked off from natural causes averaged 60 while the average number of nuts per healthy bunch was 206. The weak

and strong sprays of the first treatment gave practically identical results and so are classed together.

Treatment	Number of bunches harvested	Number of bunches attacked by Koleroga	Percentage of bunches attacked
Early spraying ...	206	50	25
Late spraying ...	177	17	10
Early *kotte*-tying ...	127	16	13
Late *kotte*-tying ...	141	30	21

As already pointed out, the poor results of the early spraying were undoubtedly due to the mistake in preparing the adhesive and they show how important the adhesive really is. The results should be compared with those obtained in the Seethoor garden. In my opinion, in attempting to spray in a rainy tropical region the use of a strong adhesive is an all-important matter. Experiments are being conducted during the current year upon this point. The late spraying where the right amount of adhesive was used gave better results than either early or late *kotte*-tying. The early *kotte*-tying gave here better results than the late, although the disease had not appeared to any appreciable extent before the late tying of *kottes*. A glance at the rainfall table shows us that the rainfall at Bellenne is decidedly higher than that at Sagar and this, of course, necessitates still more strongly a good adhesive. An examination of the nuts from the early spraying showed that the Bordeaux mixture had not adhered to the nuts as it should and this accounts for the comparatively poor results.

A comparison of badly affected bunches (loss of 100 nuts per bunch) gives us similar results to those already given :—

Treatment	Bunches harvested	Bunches badly attacked	Percentage of bunches badly attacked
Early spraying	... 206	27	13·1
Late spraying	... 177	2	1·1
Early *kotte*-tying	... 127	7	5·5
Late *kotte*-tying	... 141	14	9·9

The difference between late spraying and the *kotte*-tying is still more pronounced here, while the ineffectiveness of the early spray is not so marked when we consider the badly attacked bunches. The early tying of *kottes* is still seen to have proved more efficient than the late tying.

The total loss in bunches is shown in the following table:—

Treatment	Bunches harvested	Bunches badly attacked	Percentage of bunches badly attacked
Early spray	... 206	31·5	15·3
Late spray	... 177	11·3	6·4
Early *kotte*	... 127	9·3	7·3
Late *kotte*	... 141	23·0	16·3

From this it will be seen that the late tying of *kottes* was really not quite so effectual as the early spraying, while it was not half so effectual as the late spraying. On the other hand, the early tying of *kottes* was much more effective, but still not so effective as the late spraying, which heads the list. I may point out here that the early *kottes* were tied just about one month before those tied by any of the garden owners. Although, I think, the results this year show fairly clearly that spraying when properly done is more effectual than *kotte*-tying, no matter when it is done, I wish again to emphasize the fact that if *kottes* are to be used, they should be tied right at the beginning of the monsoon, to ensure results at all satisfactory.

In addition to the work in the experimental garden at Bellenne, spraying was done in other gardens in the neighbourhood largely for the purpose of demonstration. Although no figures are available in the case of this work, still a short description of the spraying is of importance as illustrating a side of the question which has not as yet been dwelt upon. In all the experimental gardens, spraying was done before any outbreak of disease had occurred. It is well known throughout the affected area that a very serious weakness in the method of tying covers is its frequent inability to check the disease when it has once appeared. As an instance of this may be cited a garden situated at Murthur about three miles from Bellenne. When I visited this garden first on the 18th July 1909, the disease, which had appeared about fifteen days previously, had spread over about one-third of the garden. Covers had already been tied over more than half the garden about a week previous to my visit. One tree was marked as having been observed as attacked for the first time on the day of my visit and no trees had shown

the disease farther to the leeward in the garden. On visiting the garden again on the 22nd it was found that the disease had spread over about two-thirds garden notwithstanding the fact that this very portion had been protected with covers. Thirty-six trees were counted as freshly attacked, all of them provided with covers.

In order to attempt to check the disease I had six rows sprayed right across the garden in the path of the disease. It was found, however, that smaller isolated areas had developed the disease and there was no time to spray all of these. My assistant ascertained from the tenant of the garden at the time of harvest that the crop had been almost an entire loss except on the portion that had been sprayed and that he depended upon the crop from the sprayed trees to enable him to pay the rental, something he would otherwise have been unable to do.

In another garden at Bellenne in which the disease was found to have broken out on three trees, spraying was done on the 4th July. The three affected trees were sprayed and in addition fifty-six others around them. These trees were inspected regularly throughout the monsoon and no signs of the spread were to be made out. In fact the disease was fully checked in this portion of the garden, whereas in other parts less than a hundred yards off it was very bad.

From the above there can hardly be any doubts that spraying is a much more reliable means of checking the disease in a garden once it has appeared than is the tying of coverings.

EXPERIMENTS AT THE KARODI GARDEN.

The portion of the garden which was leased comprised about half an acre, and as in the others, it was that portion of the garden where the disease had appeared first and the attack had been most serious the previous year. Spraying and the tying of *kottes* was done on the 13th and 14th of June and the weather conditions were much as already described. Throughout the stronger spray was used and spraying and *kotte*-tying were done somewhat irregularly throughout the whole leased area. Here the number of nuts which fell from natural causes was very low indeed. A count made on fifty-five healthy bunches

gave an average loss of seven nuts per bunch. In the table, therefore, only those bunches are given as diseased which had a loss of ten or over.

How treated	Bunches harvested	Bunches attacked	Percentage attacked
Sprayed	406	43	10·6
Kotte-tied ...	197	52	26·4

In the present garden the average of nuts on healthy bunches was smaller than in the gardens already described being only 157 nuts as an average from fifty-six bunches. A loss of fifty nuts per bunch should in this case be considered heavy. If we consider such bunches alone, we get the following results :—

How treated	Bunches showing loss of fifty or more nuts	Percentage
Sprayed ...	3	0·7
Tied with *kottes* ...	15	7·6

That is, five times as many bunches were badly attacked where *kottes* were tied as where spraying was done, although the number of bunches sprayed was more than double the number which had covers tied on them. A comparison of the total loss in bunches is given in the following table, counting 157 nuts as a full bunch :—

How treated	Bunches harvested	Loss in bunches	Percentage
Sprayed ...	406	7	1·7
Kotte-tied ...	197	12	6·1

Here again the results are markedly in favor of spraying as compared with the tying up of *kottes*. The loss all around is decidedly less than in either of the gardens mentioned above.

EXPERIMENTS AT HOSUR GARDEN NEAR AGUMBE.

This garden is situated in the region of the greatest rainfall to be found in Mysore. Data on the rainfall in the parts in which the various experimental gardens were situated will be given below. Spraying and *kotte*-tying were done on the 15th, 16th and 17th June. A count of fifty healthy bunches gave an average of six nuts fallen from natural causes. This seems all the more remarkable when we consider how close to the coastal plain this garden

lies and how strong the wind is in this region during the monsoon season. The great difference between loss from natural causes here and at Bellenne about equally far west is quite difficult to explain. Probably the chief reason for the small loss is to be found in the poorness of the crop and the fact that the trees were very far apart so that there was little likelihood of their knocking together when blown by the wind. The losses here, as was to be expected from the very heavy rainfall, were greater than in any of the other gardens. Moreover, a count of bunches attacked gives practically the same results for spraying and *kotte*-tying.

How treated	Number of bunches harvested	Number of bunches attacked	Percentage attacked
Sprayed ...	247	112	45·3
Kotte-tied ...	196	89	45·4

A difference is shown in the next table where only bunches having a loss of fifty nuts or over are considered.

How treated	Number of bunches with loss of fifty nuts or over	Percentage
Sprayed	31	12.5
Kotte-tied	31	15·8

We have here a small but decided difference in favor of the spraying. The following table gives the comparative losses in bunches, taking 152 nuts as an average number per bunch.

Treatment	Bunches harvested	Loss in bunches	Percentage lost
Sprayed ...	247	31	12·5
Kotte-tied ...	196	27	13·8

This also indicates an advantage in favor of the spraying although the advantage is small. In this region of excessive rainfall it stands to reason that there is great danger of the solution's being washed off and it may be necessary to use a still stronger adhesive than that already used. This is a matter which will form one of the most important lines of investigation during the coming rainy season.

EXPERIMENTS AT SEETHOOR GARDEN.

While in all the other gardens the experiments were made to test the relative values of spraying with a strong solution and adhesive and of *kotte*-tying, in this garden experiments were conducted with a view to test the relative effectiveness of different strengths of both solution and adhesive. The bulk of the experimental portion was sprayed with the strong solution and strong adhesive used in the various other gardens. A smaller number of trees were sprayed with a weak solution and weak adhesive and another number were sprayed with a weak solution and strong adhesive. The losses from natural causes here was only about five nuts per bunch, a very low number indeed. The results with regard to bunches attacked are given in the following table :—

Method of treatment	Bunches harvested	Number attacked	Percentage attacked
Strong spray and strong adhesive ...	252	39	11·9
Weak spray and weak adhesive ...	89	51	57·9
Weak spray and strong adhesive ...	45	12	26·6

From this it would appear that strong spray and strong adhesive were decidedly the best of the three. Next in point of effectiveness comes the weak spray and strong adhesive while weak spray and weak adhesive is decidedly poorer. The results here should be compared with those of the Bellenne garden where the weak adhesive used in the first spraying also proved unsatisfactory.

As a matter of fact, the above table does not give us a true picture as to the relative merits of strong spray and strong adhesive and weak spray and strong adhesive. Although under this last treatment a decidedly larger percentage of bunches were attacked, they were nearly all only very slightly damaged. Taking a loss of fifty nuts again as a bad attack, we get the following results :—

Method of treatment	Bunches harvested	Bunches showing loss of 50 nuts or over	Percentage
Strong spray and strong adhesive ...	252	13	5·2
Weak spray and weak adhesive ...	89	17	19·1
Weak spray and strong adhesive ...	45	2	4·4

These results indicate that the weak spray and strong adhesive are really quite as effective as the strong spray and strong adhesive, both having been quite effective. However, it should not be lost sight of that only comparatively few bunches were sprayed with weak spray and strong adhesive so that a more extensive trial of it appears advisable. I am, however, fairly convinced that it will prove practically as effective as the strong spray and strong adhesive and will of course be decidedly cheaper.

The total losses in bunches taking 150 nuts as an average per bunch (actual count of 65 bunches gave 154 nuts as an average) are shown in the following table :—

Method of treatment	Total number of bunches	Bunches lost	Percentage of loss
Strong spray and strong adhesive ...	252	14	5·4
Weak spray and weak adhesive ...	89	17·3	19·4
Weak spray and strong adhesive ...	45	2·2	4·9

The results are practically the same as those already given and show that both sprays where a strong adhesive was used have proved very effective.

If we sum up the results obtained from all the experiments conducted during the year 1909, we see that spraying has shown itself decidedly better than the tying of *kottes* when it has been properly done. Where, however, too little adhesive was added, the results were by no means so satisfactory. As far as experiments have been carried out, a weak or a standard solution with a strong adhesive seems to be practically as effective as a solution of double the strength with the same adhesive.

THE PREPARATION OF THE MIXTURE.

Various different formulæ are used for the preparation of Bordeaux mixture. One very commonly employed consists of 5 lbs. of copper sulphate (blue stone) and 5 lbs. of unslaked lime in 50 gallons of water. The copper sulphate is dissolved in a wooden vessel in 25 gallons of water (an earthenware one would also do, but in no case should an iron vessel be used). This is best done by placing the copper sulphate pounded up rather fine in a coarse cloth bag and suspending it in the water till it is entirely dissolved. The lime is placed in another vessel which may be of wood, earthenware or iron, and water is slowly sprinkled over it till the lumps of lime have broken up into fine particles. Then the whole of the 25 gallons of water may be poured in with constant stirring. To make the completed mixture, equal quantities of the lime water and the copper sulphate should be taken and poured into a third vessel with continued stirring. The completed mixture should have a light blue colour (on no account green) and should leave no deposit of copper on a clean knife-blade dipped into it for half a minute.

In almost all the experiments described, a mixture just twice as strong as the above was used; that is, with the same amount of lime and copper sulphate, just half the quantity of water was used.

The adhesive used was made by mixing 2 lbs. of resin, such as used by tinsmiths, and 1 lb. of washing soda and adding to this one gallon of water. The whole was then heated for about an hour till the mass had become quite clear. The strong mixture used was thus made up as follows:—

(*a*) Five lbs. of copper sulphate dissolved in 12 gallons of water.

(*b*) Five lbs. of lime slaked in 12 gallons of water.

(*c*) Two lbs. of resin and 1 lb. of soda heated in 1 gallon of water till quite clear (about an hour), (*b*) was poured into (*a*) accompanied by constant stirring and then (*c*) was added to make up the complete mixture.

The weak mixture plus strong adhesive consisted of :—

(*a*) Two and a half lbs. of copper sulphate in 12 gallons of water ;

(*b*) Two and a half lbs. of unslaked lime in 12 gallons of water ;

(*c*) Two lbs. of resin and 1 lb. of soda in 1 gallon of water.

The weak mixture plus weak adhesive was made as above except in (*c*) 1 lb. of resin and one half lb. of soda were used.

It need hardly be pointed out that any quantity can be made up at one time down to one gallon of the completed mixture, it being only necessary to keep the same proportions throughout. In practice it is always wise to make up just sufficient for one day's work as the mixture should be used fresh. Where, however, only small wooden or earthenware vessels are available it will be necessary to make up smaller quantities at a time.

Actual counts made in the sprayed gardens show that one gallon of the mixture is sufficient for spraying from ten to twenty trees, depending, of course, upon the size and number of the bunches. If we take ten as the number of trees sprayed per gallon and 400 as the average number of trees per acre, we find that 40 gallons of the mixture will be sufficient for an acre. The cost of the materials in Bangalore are as follows (wholesale rates) :—

	Rs.	a.	p.
Copper sulphate per lb.	0	4	0
Unslaked lime (best quality) ...	0	0	9
Resin	0	2	6
Soda	0	1	9

At this rate the cost of materials for spraying one acre with the strongest mixture would be about Rs. 3-4-0. It should be decidedly less than this, as I have in making the estimate taken the lowest number of tree sprayed per gallon of mixture. Cost of transport would increase the cost somewhat. In any case, accounts show that the expense of materials lies between Rs. 3 and Rs. 4 per acre. If the weaker mixture with strong adhesive were used, the cost of materials per acre would be about Rs. 1-14-0. I hope to be able to reduce the cost of materials finally to about Rs. 2-8-0 per acre.

If we now consider in comparison with this the cost

of covers, we find that they are ordinarily sold at Re. 1 per hundred. As pointed out already, there can hardly be more than enough covers procured in one garden for protecting half the trees. Taking 1,000 bunches (2½ bunches per tree) as a rather low estimate of the number in an acre, we see that if extra covers are purchased they would cost the garden owner Rs. 5 per acre or more than the cost of materials used for spraying.

In addition to the above, it has been found that spraying can be done about three times as quickly as the tying of covers. This means a further saving to the garden owner in the expense of skilled labour. The average climber ties covers on from thirty to forty trees per day (100 covers is an average day's work) for a wage of about Re. 1. That means a cost to the garden owner of Rs. 10 for his labour in the tying of covers. The same man is capable of spraying about 100 trees in a day which at the same rate of wages would amount to only Rs. 4 per acre. However, it is probable that at least for a time climbers would demand more for this new kind of work, but certainly not more than Rs. 1-8-0 per day, which would bring the cost to only Rs. 6 an acre. The cost of helpers on the ground in the one case to send up covers and in the other case to fill the sprayers would be about the same in each case.

In addition, it must not be forgotten that the number of climbers is limited as is also the time during which the work may be done, so that a more rapid method of treatment may mean all the difference between saving the whole crop and losing it. I need only cite the instance of the Murthur garden referred to above, to show the truth of this.

In conclusion, it is necessary to refer to a suggestion made by Dr. E. J. Butler, Imperial Mycologist, as a result of a tour of inspection made in the infected districts some years ago and published by him in the Journal of Indian Agriculture (for reference see below, p. 49). Dr. Butler, noting the fact that areca gardens in the southern part of the Malnad in Mysore have remained free from Koleroga, has suggested the possibility that the late harvest in that region may have something to do with the immunity to the disease. He further remarks that it might be possible by desisting from manuring the trees so heavily as is at present the practice, to delay the flowering and fruiting

season in the northern malnad sufficiently long to avoid the disease. On the other hand, he suggests that the cultivation of late-maturing varieties might have the same effect. As already pointed out in this paper, even the latest flowering areca nuts in Mysore have their flowering season in June. As the flowers are quite susceptible to disease and as the disease makes its appearance at the end of June or at the beginning of July, it will be seen that it would be difficult to avoid the disease in this way. In order to avoid infection to flowers and fruits, it would be necessary to delay the flowering season till September and considering the fact that the heaviest rains fall in the months of June, July and August, it seems to me that this would be an impossibility.

As already pointed out, if the immunity from disease in the southern malnad is due to anything but some difference in climate, or the fact that the disease has not spread there owing to the scattered nature of the gardens, it is in all probability to be accounted for by the supposition that we have to do with a distinct variety more or less immune to the disease. This matter is receiving attention at present, but it must be pointed out that the introduction of a more resistant variety of areca palm into the affected areas would necessitate experimental work extending, over ten or fifteen years, something which, unfortunately, circumstances will hardly allow me to undertake and carry out. The investigations carried on so far have been with a view to afford some immediate assistance to the garden owners of the affected tracts, but the fact cannot be too strongly emphasized that the introduction of a disease-resistant variety although it would involve the work of very many years, would, if successful, be by far the most efficient way of checking the disease.

Yet a word with regard to a "remedy" suggested to me by garden owners. Many of them have asked me why I could not give them some medicine or manure that could be applied to the bases or roots of the trees to prevent the disease from appearing. One can well understand the desire of the garden owners to obtain such a very convenient remedy. I need hardly point out, however, that any such remedy, no matter how convenient it may be, has the fatal defect of being absolutely useless, as far as preventing or curing this disease is concerned.

SUMMARY OF RESULTS.

The main results so far recorded may be summarized as follows :—

1. Koleroga of the areca palm is a disease produced by a definite fungus parasite.

2. It is, as far as at present known, restricted to two areas in India as shown on the map (Plate III). It has not as yet been recorded from any other part of India or any other country where the areca palm is grown.

3. The appearance and spread of the disease is dependent upon a high rainfall and a very moist condition of the atmosphere.

4. The disease is directly spread by means of the wind and possibly to a lesser extent by insects and birds.

5. The fungus causing the disease is able to persist from one monsoon to the next in a dormant state by means of resting spores which in all probability remain in the diseased parts, possibly also in the upper layer of the soil, through the dry season.

6. The first essential step in combating the disease is the removal and burning of all diseased parts from the affected gardens.

7. *Kottes* or coverings made of the basal sheaths of areca leaves are used extensively throughout the affected parts of Mysore and the Canara. Of these, the type used in Tirthahalli, Koppa and Nagar Taluks in Mysore (Text figure 3) is the best. *Kottes* made of tin used in a small experimental way by garden owners did not prove a success.

1. These *kottes* are under favorable circumstances fairly efficient but are likely to prove quite ineffectual in checking the disease after it has made its appearance. Moreover they cannot be provided in numbers sufficient to treat a whole garden unless an additional stock is purchased.

9. Spraying with a mixture of proper constitution invariably proved more efficient than the tying of *kottes* even when spraying was done under comparatively

unfavourable circumstances. Spraying served to check the disease where the tying of covers proved practically of no avail.

10. Materials for spraying can be supplied at a cost of Rs. 3 to Rs. 5 per acre. This will probably allow of a reduction to Rs. 2 to Rs. 3 but the results of this year's experiments are awaited before a definite statement can be made on this point.

11. Spraying can be done almost three times as fast as *kotte*-tying with the result that the cost of labour can be considerably reduced. The total cost of spraying including labour and materials will hardly exceed that of *kotte*-tying, leaving out of account the cost of preparing *kottes*. Where, however, *kottes* have to be purchased, (and this is always necessary where the work is thoroughly done) *kotte*-tying is decidedly more expensive than spraying.

WORK PLANNED FOR 1910.

The work for the present monsoon season has been so planned that spraying will be done at the expense of the garden owners. A number of sprayers have been purchased and these are being lent to the owners free of charges. They are sent in the charge of fieldmen who have been taught how to prepare the mixture. The cost of all materials as well as the wages of the climbers, etc., are being paid for by the garden owners. The fieldmen are required to send weekly reports of their work, and as soon as the disease has appeared will send weekly statements of inspections made in the various different taluks. In this way it is hoped to obtain much valuable information. Already at the time of going to press about 20 acres owned by 16 different men have been sprayed. This will probably be considerably increased before the season is ended.

In addition to the above a garden has been leased for experimental purposes and in this are being tested the relative effectiveness of various different strengths of mixture and adhesive as well as that of various different kinds of adhesive.

All the results of this year's experiments will be published in a second bulletin to be prepared as soon as this year's harvest season is over.

RECORD OF RAINFALL.

Below is given a statement of the rainfall at various different points in the malnad of Mysore during the four monsoon months, June to September, of 1909.

Rainfall	June	July	August	September	Total for 4 months
Sagar	17·56	38·30	7·52	...	63·38
Ballenne... ...	33·27	54·23	6·49	...	93·99
Karodi	28·70	69·30	11·00	7·50	116·50
Agumbe	81·70	125·30	41·94	25·81	274·75
Koppa	23·90	59·40	13·90	7·80	105·00
Kalasa	34·30	59·90	8·30	3·70	106·20

The rainfall for September for Sagar and Bellenne is not given, while that for Agumbe is for only twenty-eight days of September. The figures for Sagar do not give an accurate idea of the conditions at Hale Ikkeri five miles from there, the rainfall at Hale Ikkeri being decidedly heavier. In this connection it should be noted that Bellenne is only thirteen miles from Sagar, but the rainfall in the former place is very much heavier.

PART II.

KOLEROGA has up to the present remained practically uninvestigated from a scientific standpoint, and it is the purpose of the second part of this paper to present the result of investigations which have extended over a period of two years.

The scientific literature on the subject is, as indicated, very meagre. The first to note the disease appears to have been Cooke.[1] Unfortunately I have been unable to see Cooke's original paper, but the fact that he confuses this disease with the "Koleroga" of coffee, the "Leaf Rot" disease caused by Pellicularia koleroga, Cke., would appear to indicate that he really did not examine the disease at all but simply concluded from the identity of the popular names for the two diseases that they were caused by one and the same fungus. The veriest tyro would have not the slightest difficulty after making a microscopic examination of the two diseases in deciding that the causes were decidedly different.

The only other investigator to study the disease appears to have been Butler.[2] As, however, he was able to observe the disease only on a short tour in the affected district, and as this tour was made in August towards the end of the monsoon, his investigation was of necessity simply of a preliminary nature. He found on examination of affected leaf-sheaths and fruit-stalks a Phytophthora which he concluded "from its position, anatomical characters and the enormous quantity of spores which it produces" to be an active parasite. He also states that "there is little doubt that this is the cause of the disease." He gives a short description of the appearance of the mycelium in the infected tissues and also of the formation of sporangia and zoospores, but makes no statement with regard to the actual species under investigation. His remarks with regard to the appearance and spread of the

[1] Cooke, Popular Science Review, No. LIX, cited from von Faber, Die Krankheiten und Schädlinge des Kaffees. Centr. Bakt., (Abt. II.), Bd. 21, p. 113, 1908.
[2] Butler, Agricultural Journal of India, Vol. I, p. 299, 1907.

disease were of necessity largely based upon information furnished to him by garden owners and are therefore incomplete and in part appear to be incorrect. However, these will be discussed later.

In their "Fungi Indiae Orientalis," however, Sydow and Butler[1] identify this fungus as Phytophthora (?) omnivora, de Bary giving as habitat "in follis, fructibus pedunculisque Arecae catechu, Koppa, Mysore."

From the above it may be seen that uncertainty exists as to the real position of this fungus. In this connection it may be noted that a Phytophthora which has, following the identification of Massee[2] usually been considered as Phytophthora omnivora, de Bary has been found on several different hosts in the tropics of Asia, Africa and America, and a considerable literature has been published upon it without, however, settling beyond doubt that the fungus is really identical with the European fungus so carefully investigated by Hartig, de Bary and others. The chief host plant is the Cacao, and as extensive investigations were being carried out on the Areca fungus it seemed to me a favourable opportunity for a comparative study of the two fungi, in order, if possible, to settle their real position.

Fallen nuts affected by Koleroga almost invariably show on the surface a felty mycelial mass which usually begins to make its appearance near the base of the nut and spreads from there gradually over the whole surface. In favourable specimens this mycelium is seen to be a practically pure growth of a Phycomycete. Embedded in it are usually to be found numerous sporangia, generally oval in shape. These vary greatly in size as will be seen by consulting Plate XV, Fig. 2. The sporangia here were all drawn to the same scale. A study of the emission of the spores from these sporangia leaves no doubt but that we have here to do with a Phytophthora and not with a Pythium (see Text-fig. 1 as well as Plate XVI, Figs. 1–5). The sporangia are very readily loosened from their points of attachment and so in microscopic preparations of the surface felt-work they usually appear lying loose in the meshes of the mycelium.

As already noted, the disease is usually recognizable

[1] Sydow et Butler, Annales Mycolog., Vol. V., p. 512, 1907.
[2] Massee, Kew Bulletin, 1899, p. 1.

even before the appearance of any mycelium on the surface through the appearance of one or more patches of darker green generally beginning at the base of the nut and stretching towards the apex. Soon after this there appears a number of minute papilliform elevations which mark the points at which the fungus will break forth on to the surface. The fungus makes its exit to the surface in two different ways, by the stomata and by breaking or bursting the outer wall of epidermal cells (see Plates XII and XIII). In the majority of cases, the fungus appears to form sporangia immediately after appearing on the surface, the result being that on examination of the surface of a nut at this stage of the disease under a low power, numerous tufts of sporangia are to be seen apparently sessile upon the surface of the nut (see Plate XII, Figs. 1, 3 and 5). In other cases, however--and this seems to be especially the case where the fungus has broken through epidermal cells--mycelial threads of considerable length are formed before any sporangia appear (see Plate XII, Figs. 2 and 4, and Plate XIII). In any case hyphæ soon grow out from beneath and gradually come together to form the felt-like network characteristic of later stages of the disease. In one interesting case observed there had apparently been the beginnings of sporangium-formation on the mycelium freshly broken out on the surface of the nut, but subsequently the hyphæ had begun to grow again from the distal ends of the partially-formed sporangia (see Plate XIII, Fig. 1).

It is practically impossible to make out the system of branching of the sporangiphores by observation of the fungus as it appears on the surface of the nut. When, however, small pieces of the nut or of the nut-shell are brought into water (distilled water or rain water were usually employed) in a petri-dish, the whole process can be very readily studied. It can be seen that the first sporangium on a sporangiophore is formed terminally while the next one is formed terminally on a branch which grows out usually at a short distance below the base of the first sporangium, and that this gradually pushes the first aside so that it comes to lie laterally (see Plate XV, Figs. 1 and 3). In other words, we have here the method of sporangium formation typical of the genus Phytophthora. This, together with the method of escape of the zoospores,

leaves no doubt that the fungus belongs to this genus. A discussion of its nearer affinities will be given later.

A study of the course of the fungus in the interior of the nut-shell reveals the fact that in the earlier stages, and even in later stages in the deeper lying tissue, the mycelium is practically confined to the intercellular spaces of the parenchyma. Haustoria are scarce, but are, however, to be found on careful search. They consist of finger-like processes which are at times dichotomously branched (see Plate XIV, Figs. 1–3). Spherical haustoria such as described by Hartig[1] for his Phytophtora Fagi (Phytophthora omnivora, de Bary) were at no time to be found. The fungus does not, however, confine itself to the intercellular spaces; later on, especially in the tissues of the shell lying near the surface, it is to be seen abundantly in the interior of the parenchyma and epidermal cells so much so that the lumina seem practically filled with mycelium (Plate XII, Fig. 5, Plate XIV, Fig. 4). Thus, where the fungus breaks through an epidermal cell to the surface it appears, at least in the majority of cases, to be practically purely a physical matter. The pressure of the mycelial mass beneath bulges out the outer wall and this finally gives way. Plate XII, Fig. 2, shows such a breaking forth and the torn edges of the outer epidermal wall are clearly visible. In such cases the fungus hypha frequently enlarges to a more or less globular swelling immediately beneath the outer epidermal wall previous to bursting it. The mycelium is also to be found here and there in the vascular bundles of the shell and even in the vessels themselves.

The course of the mycelium in the nut itself cannot so easily be made out owing to the very thin nature of the cell walls of the immature tissues. In the unripe condition in which the nut finds itself at this time of the year a cross section shows a series of brownish dissepiments extending towards the centre of the nut along radial lines. The tissues here are smaller celled with somewhat stouter cell walls. Along these dissepiments the vascular bundles make their way into the centre from the net-like raphe which spreads over the outer surface of the nut.[2] The pale tissue

[1] Hartig, Untersuchungen aus dem. Forst-Botanischen Inst., München, I, 1880, p. 35.

[2] It appears unnecessary to give here a detailed description of the anatomy of nut and nut-shell. Those desiring information on this point are referred to Engler und Prantl, Pflanzenfamilien, II Theil, 3 Abt., p. 21.

lying between these dissepiments is still in the process of formation and consists of larger cells with very thin cell walls. The mycelium seems to make its way in from the surface of the nut practically entirely along the dissepiments, and from here it extends laterally into the soft tissue on each side.

As stated, the disease usually confines itself to the nuts. Occasionally, however, the tops of the trees are also infected. Butler[1] has also noted this infection of the tree-tops. As the trees in this region extend up to 70 or 80 feet in height, the disease in the top is to be noticed only after it is quite advanced. It is therefore difficult to decide just where the preliminary infection takes place. There seem, however, to be two separate ways of infection. One of these is illustrated in Plate VII. In this specimen the stalk of the bunch was completely dead and the parenchymatous portions almost entirely decayed, leaving the fibre and fibrovascular bundles free. Examination of sections of the stem taken near the point of attachment of the bunch showed the Phytophthora mycelium in abundance. The hyphæ were found here to run in the parenchyma chiefly intercellularly; they could, however, be easily traced into the fibrovascular bundles themselves where they were to be found in the interior of the parenchyma cells surrounding the vessels and proceeding from here into the vessels themselves where they pursued a fairly regular longitudinal course. In this connection it may be noted that, according to Butler,[2] his Pythium palmivorum which attacks the tops of Borassus flabellifer, and to a less extent those of Cocos mucifera and Areca catechu in the Godaveri Delta, Madras Presidency, never enters the fibrovascular bundles. On the other hand Phytophthora omnivara, de Bary, has been found even to form oospores in the tracheids of coniferous seedlings. Lindau[3] states, "In den Wurzeln der Koniferenkeimlinge trifft man die Oosporen sowohl im Rindenparenchym, als auch im Innern der Tracheiden, in denen sich die Pilzfruchte mit ihrer Gestalt dem lang-gestreckten Raume anpassen und länglich werden." As indicated in the figure, the tissue in the neighbourhood of the growing-point of the palm appears when split open

[1] Loc. cit.
[2] Butler. An Account of the Genus Pythium, etc., Memoirs of the Department of Agriculture in India. Botanical Series, Vol. I, No. 5, p. 82, 1907.
[3] Lindau, Sorauer's Handbuch der Pflanzenkrankheiten 3te Aufl., Bd. II, p. 151.

to be quite healthy as do also the bases of the leaf-sheaths enclosing it. Sections taken in the neighbourhood of the growing-point revealed no trace of the mycelium, which shows quite conclusively that the fungus has really entered into the stem by the diseased bunch stalk and not through the leaf-sheaths.

The tree-top pictured in Plate VIII shows a decidedly different condition. Here also the nuts have become diseased and have dropped off, but the bunch stalk, especially at the base, appears perfectly healthy, nor could any trace of mycelium be found in sections taken from it. On the other hand, the growing-point was badly decayed, and the course of decay seemed to have been along the line of the bases of the leaf-sheaths which form the protective covering to the tender growing-point of the stem. Preparations made from the decayed growing-point showed the typical Phytophthora mycelium in abundance together with large numbers of saprophytic organisms, chiefly bacteria. In sections of the stem taken in the neighbourhood of the point of origin of the bunch stalk, Phytophthora mycelium was also found after careful search, but it was very much less abundant than in the neighbourhood of the growing-point, and everything pointed to the probability that the disease had entered through the bases of the leaf-sheaths into the growing-point and from thence had worked its way some six inches down the stem to the region of origin of the bunches.

From the above it seems fairly certain that infection of the tree-top may take place on the one hand directly from the diseased bunch by means of mycelium growing down through the stalk and thence up to the growing-point, and on the other hand by means of independent infection of the leaf-sheaths surrounding the growing-point of the tree. Actual examination of dying tree-tops indicates that the first method is the more usual, but that the second method is also occasionally to be met with. Direct experiment, which will be detailed later on in this paper, shows conclusively that infection of the top through the leaf-sheaths by means of spores which have germinated on the outer surface can take place.

It is rather difficult to account for the rarity of attack on the tree-tops as compared with that on the bunches. Direct infection by means of zoospores germinating on the

surface of the external leaf-sheath must of necessity be rare, as during the heavy showers of the monsoon the rain water directed by the leaves runs in streams down over this outer surface and so must wash away the great majority of the zoospores that may have been deposited there. This, however, does not apply to the cases where infection has taken place through the bunch stalk and the rarity of infection even by this means must, for the present, remain unexplained.

INFECTION EXPERIMENTS.

In order to establish the parasitism of the Areca Phytophthora, extensive infection experiments have been carried out. The first of these were conducted in a small temporary laboratory set up in the heart of the affected area, during the rainy season of 1909. Inoculating material was obtained (*a*) directly from scrapings from the surface of diseased nuts, suspended in water and (*b*) from pure cultures. In addition, infection experiments were attempted by suspending healthy nuts in water over a small quantity of soil taken from a garden where the disease was prevalent or, in other cases, in water over a number of diseased nuts.

Inoculation experiments were first made with material taken direct from the surface of diseased nuts.

Sporangia were scraped from diseased nuts showing discrete sporangial sori and shaken up in sterilized distilled water. A total of forty-nine healthy nuts were washed thoroughly with distilled water and placed in dishes. They were inoculated with a loop of the watery suspension of sporangia and zoospores and the spot was marked with an inked ring. Thirty-four nuts were placed under moist bell jars and fifteen were left free to the air. At the same time the suspension was microscopically examined. The majority of the sporangia had emptied themselves. Many of the zoospores were swimming about in the water while others had come to rest and had rounded themselves off. Inoculations were made on 23rd July 1909 at 5 P.M. On 24th July 1910 a microscopical control of the inoculations was carried out. Tangential sections were made so as to remove the epidermis in the inoculated area. Sections made at 9 A.M. and 11-30 A.M. showed numerous

zoospores germinated on the surface but no penetration could be made out. In a number of cases the ends of the germ tubes had slightly enlarged into somewhat spherical swellings which resembled the appressoria formed by many parasitic fungi and described and figured by me for Sclerotinia trifolorum.[1] Here, however, also no penetration could be made out.

In sections made at 1 P.M. and 4 P.M., penetration was quite common and in every case the entrance had been accomplished through a stoma. In some cases a single zoospore had germinated near a stoma and had immediately sent down a penetration tube. In other cases a large number of germ-tubes could be seen converging from all directions to the stoma and entering closely packed together (see Plate XVI, Fig. 7). The zoospore was in many cases quite empty and also in a good many instances a part or the whole of the penetration tube had lost its protoplasmic contents. On the other hand could be found those zoospores and germ-tubes which still contained protoplasm in apparently undiminished quantity. The very characteristic appearance shown in the figure seems to indicate clearly that chemotropic action plays here a very important part in the process of penetration. This question, however, will be discussed in a subsequent paper. Sections of the shell showed in some cases penetration tubes in the substomatal chamber, but they had not yet penetrated into the parenchymatous tissue of the shell.

A large number of nuts were used for the purpose of studying the penetration so that only eleven infected nuts were left under the bell jar. A daily examination of the inoculated nuts was made, and on 28th July 1909 the first signs of the fungus appeared on the surface. Of the fifteen nuts left free to the air four showed a number of distinct sporangial bunches broken forth in or close to the area covered by the inoculating drop. Of the nuts left under moist bell jars, three still showed no sign of the disease. The rest showed the beginnings of an outbreak especially when examined with a hand lens. In one case the nuts showed the presence of sporangial tufts quite distinctly. Two of the nuts were used for sectioning and

[1] Coleman, Über Sclerotinia trifoliorum, etc., Arbeiten aus der Kaiserlichen Biolog. Anstalt für Land- und Forstwirtschaft, Bd. 5, 1907, p. 469.

the others were left. Two of the nuts which on the 28th July did not show signs of disease developed it later, so that only one nut remained uninfected. Plate V, Fig. 1. shows three nuts thus inoculated in the same way from a pure culture. The inked ring which marked the spot upon which the inoculating drop was placed is still visible.

Tangential sections of nuts showing the more advanced stage of disease showed the sporangiophores coming out from the stomata as well as breaking through epidermal cells (see Plates XII and XIII). The primary sporangiophores are, as already indicated, very short so that the sporangia appear almost or quite sessile on the surface of the nut. Later stages of growth to the formation of a felty mass enveloping the nut were as already described.

It is unnecessary to detail the results of further inoculation experiments. Suffice it to say that, with suspensions prepared from slightly diseased nuts, as with those from pure cultures in sterilized distilled water, the results were much the same and there was an average of from 80 to 90 per cent of the nuts inoculated that took the infection. Penetration was found and studied in numerous cases, and in every case the entrance of the germ-tube took place through a stoma. Penetration was to be found about twelve to eighteen hours after inoculation under conditions prevailing in the affected area, while under similar favourable conditions the disease appears on the surface of the nut about four or five days after the inoculation.

In addition to infection experiments where suspensions of the zoospores were used, others were carried out where the diseased nuts were placed in a beaker and healthy nuts suspended above them in water. Here, too, similar results were obtained. Lastly, an attempt was made to infect nuts by means of soils taken from the gardens suffering from the disease. In this connection I would recall similar experiments made by R. E. Smith[1] with his Pithiacystis citrophthora, the cause of a rot of the lemons in California. Hartig's[2] investigations on Phytophthora Fagi (Phytophthora omnivora, de Bary) also showed that the oospores of this species were capable

[1] R. E. Smith, Brown Rot of Lemon, Univ. of California Publications, Bulletin No. 190, 1907, p. 19.
[2] Loc. cit.

of remaining in the soil four years without losing their power of germination. Preliminary experiments indicate that soil or leaf-mould that has been removed from an infected tree and kept in a dry place for two or three weeks is able to infect healthy nuts if they are placed in distilled water over the soil in a beaker or other vessel. Whether this infection takes place through oospores present in the soil and just how long such soil will remain capable of infecting are subjects at present being investigated. In any case, attempts to cultivate the fungus in pure culture on sterilized leaf-mould or soil taken from the garden met with very little success. Appreciable growth could be obtained only when the leaf-mould or soil had been soaked with malt agar and even in this case the growth was sparse and only a few sporangia and no oospores could be found.

Infection experiments were also made with suspensions of zoospores directly placed on the outer leaf-sheaths of an areca-top. The course of penetration was not followed microscopically, but an examination made two weeks after the inoculation showed that the fungus had grown right through the several underlying leaf-sheaths and had attacked the growing-point. Mycelium and sporangia were to be found on the surface of the leaf-sheaths. As noted already, the fungus was here found not only in the ground parenchyma but also in the fibrovascular bundles and in the vessels themselves (see Plate XIV, Figs. 5 and 6, and Plate XV, Fig. 4). These experiments clearly show that a direct infection of the tree-top by means of zoospores is possible.

Finally, male and female flowers and flower-stalks were inoculated with suspensions of zoospores from pure cultures of the fungus. Three different stages were taken, namely, (*a*) flowers a few days before the opening of the spathe, (*b*) flowers three or four days after the opening of the spathe, and (*c*) flowers about fifteen days after the opening of the spathe. In the case of (*a*) and (*b*), flowers and flower-stalks were still quite white, while in (*c*) the female floral envelopes were already quite green and the male flowers dropped off in handling.

The inflorescences were in each case cut up into short sections a number of which were placed in petri-dishes. Each dish was placed in a larger one containing

a layer of distilled water and over it was placed a cone of moist filter paper which dipped into the water. Over this again was put a bell jar. It was attempted in this way to reproduce as nearly as possible the moist conditions prevailing in the affected area during the monsoon. In fact, this kind of moist chamber was used for many of the later infection experiments carried out at head-quarters during the dry season and was found to answer very well indeed.

Four days after the inoculation the first signs of infection could be seen on some of the male flower-stalks of (*a*). After six days the Phytophthora mycelium appeared on the surface of a section of flower-stalk in plate (*c*). In (*a*) most of the male branches were infected. The infected branches had gradually changed their whitish colour through gray to black.

After eight days there was little change except for an advance of the disease on the sections already infected. On plate (*a*) all four branches bearing male flowers were infected. Of the five branches bearing female flowers, three were infected. On plate (*b*) no infection had taken place, there being nothing to be found but a small amount of saprophytic mycelium On plate (*c*) only one branch bearing female flowers had become infected, the other four had not.

Although the results were not as good as might be desired, still they show clearly that the fungus is able to infect both flowers and flower-stalks. It must not be forgotten that this experiment was carried out in February during the driest time of the year and that the fungus material used for inoculations had been growing in pure culture in the laboratory for about seven months. It should be further noted here that, notwithstanding every effort to reproduce the climatic conditions existing at the time the disease is prevalent, infection experiments have not been so uniformly successful in Bangalore during the dry season as were those carried out in the affected area during the monsoon.

It is hardly necessary to add in concluding this description of inoculation experiments that in all cases the material used consisted of a suspension of zoospores in water. This is without doubt the chief, if not the only, natural mode of infection. Further, in no case was the

surface of the material to be inoculated wounded in any way. In fact, every attempt was made to reproduce natural conditions as far as that is possible in a laboratory.

MORPHOLOGY OF THE FUNGUS.

The mycelium of the Areca Phytophthora possesses the usual Phycomycete characters. The protoplasmic contents are marked by their granular appearance and are loaded with fat for the most part in a fine state of division. Septa are comparatively rare, appearing in the vegetative mycelium only at an advanced stage. The hyphæ vary much in breadth reaching a width of 8 or 9μ.

The sporangiophores in water-cultures appear rather irregularly branched and agree well with the description given by de Bary[1] for those of Phytophthora omnivora (see Plate XV, Fig. 3). The sporangia vary considerably in size and shape as indicated in Plate XV, Fig. 2. Extreme measurements were $20{\cdot}6\mu \times 30{\cdot}1\mu$, $45{\cdot}4\mu \times 51{\cdot}2\mu$, and $43{\cdot}3\mu \times 71{\cdot}0\mu$. Fairly frequently they possess a sort of apophysis such as that figured by von Faber for the Cacao Phytophthora. The development of a sporangium is shown in Plate XV, Fig. 1. The drawings here were all made to the same scale with a camera lucida and the figure explains itself. It is interesting to note that the whole development up to the emission of zoospores occupied only four hours. The formation of a second sporangium on a branch which grows out a short distance below the point of attachment of the first one is also clearly shown in the figure.

The formation and emission of zoospores in a sporangium is clearly influenced by external factors, chief of which is a certain strength of light. This applies not to the Areca Phytophthora alone but appears to be a characteristic of many Phycomycetes, though I have been unable to find any reference to it in the literature at my disposal. In the case of the Areca Phytophthora, if a water culture containing sporangia or a suspension of sporangia in water be placed on the stage of a microscope and be illuminated by means of mirror and condensor, almost invariably within ten or fifteen minutes, if the culture is healthy, the

[1] De Bary, Zur Kenntnis d. Peronosporeen, II. Phytophthora omnivora, Bot. Ztg., 1881, p. 587.

zoospores commence emerging from the sporangia in numbers. If cultures are kept in the dark, the sporangia can be kept intact for over a month, and later as soon as they are brought out to the light on the microscope stage, the spores commence emerging after ten or fifteen minutes. On the other hand, cultures of a few days' growth will show exactly the same phenomenon. As indicated above, if a sporangium be kept in the light on the stage from the time it begins to form till the time it empties, it is found able to complete the whole cycle in about four hours at the ordinary prevailing temperature.

Whether the formation of the sporangia themselves is partially dependent upon the admission of light, is not clear from the experiments performed by me. My first experiments seemed to indicate that light played no part, but in this case a rather frequent microscopic control may have allowed for an amount of light getting to the cultures sufficient to bring about the formation of sporangia. In a later experiment twelve pure cultures in petri-dishes were prepared and kept in a dark cupboard. These cultures were prepared on 5th July 1909 and underwent a very hurried examination on 9th July 1909, to see that they were growing. They were next examined on the 14th August or about five weeks after they were prepared. There was a well-marked growth of mycelium but no sporangia in any of the cultures. Six of the plates were placed at the window and the other six were returned to the dark cupboard. On the 16th August the plates left at the window were examined. Four of them were found to contain sporangia and two none. Of the six returned to the cupboard none showed any formation of sporangia. Examination later gave no change in the result as regards the cultures kept in the dark. The water of the two cultures at the window which had formed no sporangia was changed on the 21st August. On the 24th a very few sporangia were to be found in one of the two plates but the other culture remained sterile. No further change took place. Klebahn[1], in his recent paper on Phytophthora Syringæ, gives an interesting account of experiments on the emission of zoospores in that species. The fungus apparently does not form sporangia normally on

[1] Klebahn, Krankheiten des Flieders, Berlin. 1909.

the host plant (Syringa vulgaris) and he succeeded in obtaining them only by growth in water cultures. In order to produce an emission of the oospores he found it necessary to replace the water of the culture by a fresh supply which had been saturated with oxygen. In the case of Phytophthora omnivora which he also studied, this was unnecessary as the sporangia readily gave off the zoospores. He does not appear to have made any observations upon the influence of light either on the formation of the sporangia or on the emission of the zoospores.

Time has failed for the carrying out of exact experiments on the factors affecting the formation of sporangia and the emission of zoospores, but it is proposed to take up this very interesting question in the near future.

The question of the influence of light on the formation of sporangia and the emission of zoospores has a decided practical interest in the case of the Areca Phytophthora. As already noted in the first part of this paper, the general opinion of garden owners throughout the whole infected tract in Mysore and elsewhere is that the spread of the disease is very much favoured by weather conditions where rain and sunshine alternate every few hours. Such a belief is, of course, the result of years of observation and I have as yet not had the opportunity to form an independent opinion on the question. If such be really the case, it seems highly probable that the fact is connected with the influence of light on the emission of the zoospores. Germination of the sporangia direct as condia has been extremely rarely seen although hundreds of cultures and preparations containing sporangia have been examined. At times a number of the spores do not succeed in escaping and these may germinate *in situ*[1] sending out germ-tubes through the wall of the sporangium but ordinarily all the spores escape. A rapid alternation of rain and sunshine would favour the emission of zoospores in large numbers, while the showers in between would keep the air saturated with moisture and the rain along with the wind would allow the zoospore-laden raindrops to be carried from one bunch and one tree to another.

The zoospores are the typical oval biciliated bodies of the genus and agree with the description given by de Bary,

[1] Cf. Hartig. loc. cit., p. 44.

Hartig, von Faber and others for Phytophthora omnivora and Cacao Phytophthora. As noted by Klebahn[1] for Phytophthora Syringæ, the cilia are unequal in length, the anterior one being distinctly shorter than the posterior. They are already at least partially formed in the sporangium before any have escaped and on fixed specimens the lines of demarcation can be readily made out (see Plate XVI, Fig. 1, and Text-fig. 1). No special investigation of the process of escape of the zoospores has been made. The apex of the hyaline papilla has a very thin wall and this portion either bursts or becomes dissolved, allowing first the escape of the transparent fluid or semi-fluid substance contained in the hyaline papilla. This is followed by the spores (see Plate XVI, Fig. 4, and Text-fig. 1). They may emerge singly or in clumps but usually a number of them attached together escape at first and gradually separate from each other. Not infrequently two zoospores can be seen for some time attached together and may be even swimming about in this condition, which goes to indicate that separation in the sporangia is commonly incomplete. Frequently only a portion of the zoospores escape together at the beginning and the remainder become entirely separated and actively motile inside the sporangium. These one by one approach the opening and make their escape by a sort of amœboid motion. Not infrequently a number of them fail in the attempt to escape and after rounding themselves off germinate *in situ*, sending out germ-tubes through the wall of the sporangium.

The zoospores after swimming about for a certain period of time come to rest, round themselves off and soon afterwards germinate, sending out one or more germ-tubes (see Plate XVI, Fig. 6). The following experiment gives data as to the periods of swimming, etc., under the conditions of temperature existing in the affected area.

2-20 P.M.—Pure culture containing sporangia placed on stage of microscope.

2-30 P.M.—Zoospores commencing to come out of sporangia.

2-45 P.M.—Twenty-nine drops of water containing swimming zoospores placed on slides; all the zoospores were still swimming.

[1] Loc. cit.

3 P.M.—In every one of the drops some zoospores have come to rest. In some few drops all have done so. There is every gradation up to drops in which the great majority of the spores are still swimming.

3-15 P.M.—In twelve of the 29 drops all the zoospores have come to rest. In others a gradation as before. No spores have begun germinating.

3-30 P.M.—In practically all the drops germination has begun.

3-45 P.M.—Germination general.

4 P.M.—In twelve drops zoospores still swimming.

4-25 P.M.—A very few zoospores still swimming in a few drops.

4-45 P.M.—Zoospores have all come to rest, most of them are germinating.

From the above it can be seen that under conditions such as exist in the affected area, (*a*) under favourable conditions of light, emergence of zoospores begins after about ten minutes, (*b*) the length of the swimming period varies from about 30 minutes to 2½ hours and (*c*) germination commences or becomes visible from 20 to 30 minutes after the zoospores come to rest.

The extreme rapidity of the whole process enables us better to understand the very rapid spread of the disease once it has appeared in a garden.

Sexual organs.—Neither sexual organs nor oospores have as yet been found on diseased nuts or diseased tops from infected gardens although a long search has been made for them. An attempt to cultivate the fungus from old diseased nuts which had remained in the garden for a year, also failed. It seemed then that the fungus resembled Phytophthora infestans in lacking oospores entirely. However, these organs were found later both in laboratory cultures and on other species of plants inoculated with the fungus. In the laboratory the sexual organs were found on pure cultures growing on inoculated areca nuts which had been previously removed from their shells and placed over water in sterilized Roux-tubes.

It is, of course, premature to state that the fungus does not form sexual organs under natural conditions in the areca gardens. In fact it seems almost certain that such does occur, otherwise it would be difficult to explain the carrying over of the disease from one year to the

next. From the careful investigation already made it appears certain, however, that such formation must be of comparatively rare occurrence. Considering the abundance with which they are formed in aseptic cultures on areca nuts, it seems highly probable that the reason for their non-appearance or rarity under natural conditions must be sought in the influence of the saprophytic organisms which are to be found in abundance on every nut showing a stage of the disease at all advanced. It is these organisms which really produce the rot of the nut, for aseptically taken nuts inoculated with pure cultures show no signs of such rotting. The rot resulting from the attack of other Phytophthoras and related fungi has also been shown to be largely of secondary origin.

The saprophytic organisms most commonly to be met with are various different kinds of bacteria and a species of Tubercularia whose pinkish cushion-like fructifications are to be found on the surface of the shell of almost every badly diseased nut. That the saprophytic organisms exercise a marked influence upon the growth of Phytophthora is quite certain. At times in the case of artificial infections they so masked or overgrew the Phytophthora on the surface of the nut that the latter formed no sporangia whatever. As it is impossible to identify this Phytophthora by means of the mycelium, it was found necessary in such cases to remove the nut as aseptically as possible from the shell and grow it in water culture. When this was done formation of typical sporangia readily took place and the infection was thereby established.

The fact that the Areca Phytophthora has been successfully used in inoculating other plants suggests the possibility that the fungus has other host plants in the infected area. Unfortunately, the formation of sexual organs and the infection of other plants were established only after the end of last year's monsoon, so that an investigation of this side of the question could not be taken up. It will form one of the most important subjects of study during the coming monsoon. The discovery of intermediate hosts, especially if it be found that the fungus regularly produces sexual organs and oospores upon them, would, needless to say, be a matter of great practical importance.

Growth of sexual organs on inoculated areca nuts

will be described in a future paper. Suffice it to say here that the sexual organs seemed to be formed always on the mycelial felt on the surface of the nut and not in the nut tissue itself. The formation of the oogonia and the antheridia followed quite closely that of Phytophthora omnivora so carefully described by de Bary[1]. The antheridium and oogonium arise close together as branches of the same thread and in only one doubtful case on another host did the antheridium appear to rise from a separate thread. As to the time of formation of the two organs it appears that, in some cases at least, the antheridium begins to develop first. The antheridium arises as a terminal swelling on a thread and soon after, the oogonium develops, as a branch immediately beneath it. This branch grows past the antheridial branch and becomes closely applied to it, at the same time swelling out at the end. The oogonium on being rounded off thus comes to lie immediately above the antheridium which is applied to its base. The formation of oogonia and antheridia thus bears a striking resemblance to the formation of two sporangia on the same sporangiophore. How far this resemblance has to do with a real relationship between asexual and sexual organs, must remain for the present simply a matter of conjecture.

A similar course of development is described by Clinton[2] for the sexual organs of Phytophthora phaseoli. De Bary, on the other hand, would appear to think that the oogonium begins to be formed slightly before the antheridium. He adds, after stating the two organs begin to be formed "fast gleichzeitig," "ob die Anlegung des Oogons jener des Antheridiums doch um kurze Zeit vorausgeht war bei dem gewöhnlich dichten Gewirre von Zweigen und Zweiganlagen an fructificierenden Orten nicht möglich mit Sicherheit festzustellen."

The differentiation of the oosphere and the fertilization processes have been studied only in a preliminary manner on living material. They agree very closely with the careful description given by de Bary for Phytophthora omnivora. The cytological aspect of fertilization has, as far as I am aware, not yet been investigated in any species of this genus. Work on it has been begun and a detailed study of the

[1] De Bary, Beiträge zur Morphologie and Physiologie der Pilze IV, 1881, p. 22.
[2] Clinton, 31st and 32nd Report of Connecticut Agr. Expt. Station, 1907-08, p. 901.

formation of the sexual organs and of the fertilization processes will form the subject of a second paper. Plate XVII, Figs. 1, 2 and 3, show different stages of the same organ, and were drawn at the intervals indicated to show especially the development of the oosphere. Fig. 1 shows an early stage shortly after the formation of the oogonium has been completed and it has been separated off by a wall from the mycelial thread bearing it. The protoplasm in both oogonium and antheridium is finely granular with a number of oil globules showing. In the oogonium is situated a comparatively large vacuole and this seems to be universally present at this stage in its development. The fate of this vacuole was not definitely followed, but it disappears during the differentiation of the oosphere, and its contents are probably distributed in the periplasm.

Just preceding the formation of the oosphere is to be noted a gradual change in structure of the oogonial contents, the whole protoplasm becoming charged with large fat globules as shown in Fig. 2. The differentiation of the oosphere seems to take place by a process of contraction or concentration of the fat-laden protoplasm. Such a contraction is seen, at least at times, to be accompanied by a more or less amœboid change of outline. This feature is to be seen clearly marked in Plate XVII, Figs. 4–7, which are reproduced from drawings made with the camera lucida at the intervals of time indicated; the amœboid change of outline in the contracting oosphere is shown clearly in Figs. 5 and 6, while in Fig. 7 the definitive spherical shape of the oosphere has been assumed. Just about the time the oosphere has rounded off, the penetration tube of the antheridium is to be seen. The course of fertilization seems to be as described by de Bary for Phytophthora omnivora, but a passage of granular protoplasm from the antheridium to the oogonium could not be made out definitely. At a time when the penetration tube is still visible a wall commences to be formed about the oosphere thus marking the formation of the oospore. This wall increases in thickness and takes on a distinctly yellowish-brown tinge as do also the oospore contents, thus giving the structure and appearance of the mature oospore. The changes that take place in the antheridium are those already described by de Bary. Only a part of the antheridial contents passes over into the oospore at

the time of fertilization and the remainder, after persisting for some time, degenerates, so that where mature oospores are examined empty antheridia are still frequently to be found attached to the surrounding oogonial wall. Plate XVIII, Figs. 1–3, show the mature oospores. Although these drawings were made several months after the oospores had been formed, the walls of both oogonium and antheridium were still intact.

The germination of the oospores has not yet been actually observed although a number of them have been kept in hanging drops in pure water for about seven months. In one such hanging drop prepared on the 1st December 1909 two sporangia were observed on 10th June 1910. As this culture was quite pure, these must probably have arisen through the germination of an oospore, for it seems to me that, in the frequent examinations of the drop cultures, I could hardly have overlooked them from the start. Unfortunately, most of the oospores in this culture were so embedded in the mycelium that no direct connection could be made out between the hyphæ bearing these sporangia and an oospore.

Pure Cultures of the Areca Fungus :—Along with inoculation experiments it was decided to attempt its growth in pure cultures. As far as the literature available indicates, four species of Phytophthora have been grown in absolutely pure culture up to the present. Phytophthora infestans was obtained and studied in pure cultures first by Matruchot and Molliard[1] and later by Clinton[2], and Phytophthora Phaseoli was isolated and grown in pure culture by Clinton[3]. Klebahn, in the paper already cited, gives an account of pure cultures of Phytophthora Syringæ and Phytophthora omnivora. The statement made by Matruchot and Molliard and also cited by Clinton, that van Breda de Haan had isolated and grown in pure culture his Phytophthora Nicotianæ, seems to rest on a misapprehension. I have read van Breda de Haan's[4] paper rather carefully and can find in no part of it a statement that he had obtained a pure culture.

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[1] Matruchot et Molliard, Sur la Culture pure de Phytophthora infestants de B. Agent de la Maladie de la Pomme de Terre, Bull. de la Soc. myc. t. XVI, p. 209 ; also Sur la Phytophthora infestans, Ann. Myc. Vol. I, 1903, p. 540.

[2] Clinton, Downy Mildew or Blight, Phytophthora infestans (Mont) de Bary, of Potatoes II, 29th Report of the Conn. Experiment Station, 1905, p. 314.

[3] Clinton, Downy Mildew or Blight, Phytophthora phaseoli, Thaxt., of Lima Beans, same report, p. 278.

[4] Van Breda de Haan, De Bibit-ziekte in de Deli-tabak, Med. uit S'Lands Plantentuin, 1896.

It appears to be very difficult, if not impossible, to isolate the Phytophthoras by the ordinary plate method on agar or gelatine. On account of their comparatively slow growth on these media they are almost certain to be overgrown by other organisms, either fungi or bacteria. It is necessary, therefore, to attempt some other method. Matruchot and Molliard in their investigation of Phytophthora infestans used as substratum living pieces of potato tuber taken aseptically and placed in sterilized tubes. These tubes they inoculated with conidia from a piece of Phytophthora-infected potato kept for a couple of days in a moist chamber. With care they were able by this means to get a number of pure cultures. Clinton notes the practical impossibility of accomplishing the isolation of Phytophthora infestans by means of petri-dish cultures and also indicates that the method adopted by Matruchot and Molliard is unsatisfactory. He attempted two methods of isolation, both of which proved successful; one was to cut out aseptically from slightly diseased tubers pieces of diseased tissue and to insert these in sterilized tubes on the nutritive medium and the other was to hang infected leaves over aseptically taken pieces of potato tuber so as to allow the conidia to drop on to the tuber. Clinton isolated Phytophthora Phaseoli (from Phaseolus lunatus) also by the aseptic method, which he describes as follows:—

"The best method for securing pure cultures is to transfer into the culture tubes pieces of the tissue or, better, whole seeds which contain mycelium of the fungus, taking these from the interior of pods showing the freshest and least contaminated external growth of the mildew." Further, "other fungi especially Fusarium closely follow the development of the mildew and unless seeds or tissues in a very early stage of infection are selected, some mycelium of these or bacteria will also be included and eventually spoil the cultures."

In the attempt to isolate the Areca Phytophthora the efforts to separate it on agar plates had soon to be abandoned as impracticable. The method found by Clinton to be most useful was, on the other hand, found to answer exceptionally well. Nuts showing an early stage of infection with very little growth of Phytophthora on the surface were sterilised externally by dipping in 80 per

cent alcohol and igniting. The shell was removed by a flamed knife and then the nut, either whole or in pieces, was inserted into a sterilised Roux-tube with water in the bottom. By this method about 50 per cent of pure cultures could be obtained. A fairly copious growth of mycelium appeared on the surface within two or three days and from this transfers were made on to various different media. Where material for infection experiments was required, nuts which on growth were found to contain pure cultures of the Phytophthora were removed aseptically to a sterilised petri-dish and cut with a flamed knife into small pieces. These pieces were distributed in sterile petri-dishes containing sterilised distilled water or rain water, and within a few days a copious growth of mycelium and sporangia was obtained.

Aseptic transfers of slices of slightly infected nuts direct to water in petri-dishes also yielded a goodly number of pure cultures which gave abundant sporangia and zoospores for inoculation purposes. Occasionally the petri-dish cultures became contaminated, but as this was almost invariably by either a Cephalosporium, a Fusarium, or a Penicillium, there was no danger of confusion, nor could there be any doubts as to results of infection experiments, when such material was used.

Growth of the fungus on artificial media.—As soon as pure cultures were obtained, cultivation was attempted on various sterilised media. The following media were tried:—Malt extract, malt agar, bouillon agar, potato agar, potato cylinders, boiled rice; and the following notes indicate the nature of the growth on each:—

Malt extract.—Growth at first chiefly submerged, but later, after about a week good growth was found on the surface with formation of surface film. This became quite thick and tough and was found to be made up of a very densely woven mass of mycelium. Neither sporangia nor sexual organs were formed (this even after three months).

Malt agar in slant tubes.—The growth was moderately good but mostly in the substance of the medium raising itself very little above the surface. On the surface the mycelium branches and rebranches in a most complicated coral-like fashion bearing considerable resemblance to the simpler types of organs of attachment (Haftor-

ganen) found in cultures of Botrytis, Sclerotinia, etc., (see Plate XVII, Fig. 10.) Here also no trace of reproductive organs could be found. If, however, small pieces of agar containing mycelium were brought into distilled water a growth with formation of sporangia took place. In one of the later cultures a very few sporangia were found on more or less contaminated malt agar, but the sporangium formation was very sparse.

Bouillon agar.—Growth nil.

Potato agar.—Growth similar to that on malt agar but not so copious.

Potato cylinders.—Very abundant growth of mycelium which covered practically the whole of the cylinder. Examination at the end of about three months showed the hyphæ mostly empty but no sign of sporangia or sexual organs either in the tissue of the tuber or on the surface. The potato gave off a fairly strong smell of ammonia and showed a marked ammonia reaction with Nessler's reagent. The potato had not rotted, nor did the starch grains appear to have been at all attacked although the tissue was crowded with mycelium.

Boiled rice.—Growth was also quite copious on this medium, but here again no sign of reproductive organs was to be made out.

In addition to the above, cultures were made on sterilised flies in distilled water.[1] These in a petri-dish gave quite an abundant growth of mycelium and a particularly luxuriant formation of sporangia. In fact this was found to be one of the very best methods of obtaining pure material for infection experiments.

Experiments were also made on the growth of the fungus on sterilised soil and leaf-mould taken from gardens in the infected area. On neither did the fungus grow to any appreciable extent and it was only after the addition of malt extract that the fungus obtained a growth that was noticeable to the naked eye. An examination of such cultures about three months after their inoculation showed mycelium and a few scattered sporangia which appeared to be dead as their contents were pale and vacuolated and as none of them could be made to give off zoospores.

The purpose of this last experiment was to make out, if possible, whether the fungus could live in the soil as a

[1] Cf. de Bary, Bot. Ztg., 1881.

saprophyte as it seemed quite possible that it might be able to hold itself over from one season to another in this way. In this connection may be noted the interesting fungus causing a rot of the lemon, studied by R. E. Smith[1] and named by him Pithiacystis citrophthora, which is able to live as a soil fungus. Oospores of Phytophthora omnivora are also capable of remaining dormant in the soil, but as far as I am aware, there is no record of this fungus growing as a soil organism. As already noted, no oospores of the Areca Phytophthora have as yet been found on or in nuts actually infected in the gardens, although in all probability such will yet be found. In this case all difficulties with regard to the wintering of the fungus will be removed.

THE RELATIONSHIPS OF THE ARECA PHYTOPHTHORA AND THE CACAO PHYTOPHTHORA.

It has already been remarked that the specific position of the Areca Phytophthora is not at all established. The same also applies to the Cacao Phytophthora which, following Massee, is usually considered as P. omnivora. Massee's description and figures are quite inadequate to allow of a decision in the matter. As Wilson[2] has pointed out, both description and figures might apply equally well to another species. He notes that the conidia as figured by Massee are somewhat more elongate than is usual in Phytophthora omnivora and adds, "This taken with the habitat suggests that the pod-rot of Cacao may be caused by a distinct but closely related species." Busse[3], Petch[4] and von Faber[5] have also expressed doubts as to the correctness of Massee's classification. Petch states, "The pod disease of Ceylon appears to be due to Phytophthora, but whether P. omnivora de Bary, is doubtful as the germination of the conidia has not been observed." Von Faber remarks, in the same connection,

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[1] Loc. cit.
[2] Wilson, Studies in N. A. Peronosporales II, Bull. Torrey Bot. Club, 1907, p. 34.
[3] Busse, Reisebericht der pflanzen-pathlogischen Expedition des kolonial-wirtschaftlichen Komitees nach West-Afrika, Der Tropenpflanzer, 1905.
[4] Petch, Ceylon Administration Reports, 1906, Part IV, Report of the Government Mycologist, p. C5.
[5] Von Faber, Die Krankheiten und Parasiten des Kakaobaumes, Arb. a. d. Kaiserl. Biolog. Anst. Bd. 7, p. 199., 1909.

"Seine (d. h. Massee's) Annahme aber, dass der Erreger mit Phytophthora omnivora, de Bary identisch ist, fehlt die Begründung," and further "Solange nicht exakt-ausgeführte Infektionsversuche die Übertragbarkeit des Pilzes auf andere Pflanzen bewiesen haben, müssen wir die Artfrage unentschieden lassen."[1] As to the morphological characters distinguishing the Cacao Phytophthora from P. omnivora, von Faber notes the following :—

1. While de Bary found frequently a rich branching of the sporangiophores of P. omnivora when they were submerged in water, von Faber could not find any such rich branching in the case of the Cacao Phytophthora. Rarely were more than one or two lateral branches formed.

2. De Bary found frequently thirty to fifty zoospores escaping from a single sporangium, while von Faber could never find more than twenty.

3. The oospores of the Cacao Phytophthora are, according to von Faber, considerably larger than those given for P. omnivora. De Bary found diameter of 24-30μ for mature oogonia while von Faber observed oospores with a diameter of 45μ.

Through the courtesy of Mr. T. Petch, Government Mycologist of Ceylon, I was furnished with excellent fresh material of the Cacao Phytophthora which was very suitable for study and which moreover permitted a ready isolation of the fungus by the aseptic removal of slightly diseased portions of the pod and the beans.

As von Faber has but lately published a rather full description of the morphological characters, it is necessary only to note the respects in which my examination gave different results.

As to the growth of sporangiophores under water, in my early cultures I obtained results similar to those noted by von Faber. In comparison with the Areca Phytophthora the sporangiophores were small and with few sporangia. Later, however, cultures were obtained in which the sporangiophores were just as complicated as those described for P. omnivora by de Bary. The results of the examination of hundreds of cultures of these two Phytoph-

[1] It should be noted here that Petch in the above cited Report states that the Cacao Phytophthora attacks also the fruits of Hevea brasiliensis and Artocarpus incisa.

thora forms show that the complexity of the sporangiophores and the size of the sporangia are very variable indeed and must be used only with the greatest caution in dividing one form from another. The measurements of oospores showed a decidedly larger size as an average than that given for P. omnivora, although I found none that measured 45μ. The average of 30 measurements of oospores found in Cacao tissue and in artificial cultures gave a diameter of 33·3μ; the extremes were 41·2μ and 22·4μ. Another feature touched upon by von Faber seems much more important than the size of the oospores, that is, the question of the absence of antheridia. Von Faber states, "Oogonien und Antheridien konnte ich nicht wahrnehmen." My own examination gave results quite similar to those of von Faber. A large number of preparations containing oogonia and oospores both in Cacao-pod tissue as well as from artificial cultures and other host plants were examined and in no case could any trace of antheridia be found. In a large number of cases the original stalk of the oogonium could be seen, but there was no evidence of any antheridium attached thereto. In some examples, from the mode of attachment of the oogonium stalk it appeared as if the oogonial wall had become directly the wall of the oospore by a process of thickening. This was in all probability not the case, as the oospore almost always fills the oogonial cavity so completely that the oogonial wall can be made out only with difficulty (see Plate XVIII, Figs. 4–9). This may account for the fact that von Faber was unable to find oogonia in the material examined by him. Massee's two figures of oospores show no indication of an antheridium, although in one of them the oogonial wall and stalk are figured quite clearly. As far as I am aware, there is no record of the finding of antheridia in the Cacao Phytophthora and all the evidence at hand goes to indicate that the oospores, at least in the majority of cases, develop parthenogenetically. In this respect the Cacao Phytophthora contrasts strongly with the form on areca where antheridia seem to be universally present and where the remains of them could be found attached to the oogonial wall long after the oospores had been fully formed and were quite mature (see Plate XVIII, Figs. 1–3).

Cultures on artificial media.—To serve as a further comparison with the Areca Phytophthora a number of

transfers to artificial media were made. The results were as follows:—

Malt agar.—The growth on this medium was much like that already described for the Areca Phytophthora. While, however, the mycelium of that fungus remained quite free from sexual organs here, there was a very marked development of oogonia and oospores. The oospore almost invariably filled the oogonium quite full. No trace of antheridia could be found. In addition to oospores, there was a sparse formation of sporangia.

Bouillon agar.—Scanty mycelial growth occurred, but without formation of oogonia or sporangia.

Potato agar.—Growth much as on malt agar, but not so copious.

Potato cylinders.—Copious mycelial growth as in the case of the Areca Phytophthora. Here again oospores were to be found in abundance and as before there was no sign of antheridia.

Aseptically taken areca nuts in Roux tubes.—Cultures examined about three months after inoculation from a pure culture showed a fairly copious mycelial growth on the surface of the nut. Embedded in this mycelium were a few sporangia and fairly numerous oospores. Here again, although a large number of oospores were carefully examined, in no case could any trace of antheridium be found.

The following are measurements of oospores from Cacao-pod, areca nut culture, and malt agar culture:—

Oospores from Cacao-pod. Average of 10, 32·0μ. The largest measured was 38·0μ, the smallest 22·4μ.

Oospores from areca nut culture. Average of 10, 33·5μ. The largest measured was 41·2μ, the smallest 23·8μ.

Oospores from malt agar. Average of 10, 34·5μ. The largest measured 40·0μ and the smallest 28·0μ.

As will be seen, the measurements decidedly exceed those given by de Bary for P. omnivora but do not reach those of von Faber. De Bary's measurements are given for oogonia and not for oospores. He states, "Die Oospore erfüllt zur Reifzeit den blasigen Teil des Oogoniums durchschnittlich etwa zu zwei Dritteln bis vier Fünfteln. Im Vergleich zu Peronospora-arten sind die beschriebenen Organen klein, den Querdurchmesser des kugeligen oberen Theils reifer Oogonien fand ich durch-

schnittlich 24μ–30μ gross, oft auch kleiner als 24μ." Taking the oospores as four-fifths the diameter of oogonia, we get a diameter of 19μ–24μ for the oospores.

On the other hand, comparing the oospores of the Cacao Phytophthora with those of the Areca Phytophthora, we get practically the same measurements, though the oogonia of the latter are slightly larger. Measurements of the oospores of the Areca Phytophthora gave a diameter of 23μ–36μ.

From a study of the morphological characters of the two fungi we should come to the conclusion that we have here to do with forms closely allied to P. omnivora but yet distinct from it. The absence of the antheridia in the case of the Cacao Phytophthora speaks particularly strongly in this direction.

In order to gain a further knowledge of the affinity of the two fungi a number of inoculation experiments on other plants were carried out. As is well known, Phytophthora omnivora has been found capable of infecting a very large number of plants. These may be classified as follows:—

Host	Author
Cereus giganteus	Lebert and Cohn.[1]
Melocactus nigrotomentosus ...	
Seedlings of Fagus, Picea, etc. ...	Hartig.[2]
Sempervivum species, *e.g.*, S. albidum, S. tectorum, S. glaucum, and S. stenopetalum	Schenck.[3]
Cleome violacea	De Bary.[4]
Alonsoa caulialata	
Schizanthus pinnatus	
Gilia capitata	
Fagopyrum marginatum	
F. tartaricum	
Clarkia elegans	
Epilobium roseum	
Cereus speciosissimus	
„ peruvianus	
Seedlings of Lepidium sativum, Oenothera biennis and Salpiglossis sinuata	

[1] Lebert u Cohn, Cohn's Beiträge z. Biolog., I, 1870, p. 51.
[2] Hartig, loc. cit. and Lehrbuch d. Baumkrankheiten.
[3] Schenck, Sitzungsberichte d. naturforsch. Ges., Leipzig, 1875, p. 70, also Bot. Ztg., 1875, p. 691.
[4] De Bary, loc. cit. 1881,

Host	Author
Calceolaria rugosa and fruits of Pyrus malus and Pyrus communis ...	Osterwalder.[1] Marchal.[2] Bubak.[5]
Seedlings of Myristica fragrans ...	Zimmermann.[3]
Aralia quinquefoliata var. Ginseng ...	Hori.[4]

The conclusions of Hori and Zimmermann that the forms they investigated really belonged to P. omnivora seem to be based simply on morphological similarities. I have not, however, had access to Hori's original paper, so may be mistaken with regard to him.

As many as possible of these and closely related species were obtained and experimented upon, *viz.*, Cereus formosus, Clarkia elegans, Schizanthus wisetonensis, Oenothera biennis, Salpiglossis variabilis. Material for these experiments was kindly furnished to me by Mr. G. H. Krumbiegel, Economic Botanist and Superintendent of Government Gardens in Mysore. In addition to the above, infection was attempted on Solanum melongena, Lycopersicum esculentum and Solanum tuberosum. In this connection it may be noted that de Bary's infection experiments on Solanum tuberosum and Lycopersicum esculentum[6] were entirely without results. He states: "Völlig resultatlos blieben dagegen zahlreiche Versuche der Infektion von Solanum tuberosum sowohl junger Blatter und Laubstengel, als junger Knollen, und von Keimpflanzen des Lycopersicum esculentum, also der Hauptwirthspecies der naheverwandten Phytophthora infestans."

In the case of all the species experimented upon, successful infection was accomplished with both fungi, with the exception of Solanum tuberosum. It seems probable that seedlings of this plant also would have proved susceptible but they were not available. In the case of Solanum melongena and Lycopersicum esculentum, only seedlings proved susceptible. Inoculations of plants about six inches high were unsuccessful.

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[1] Osterwalder, Centralblatt f. Bakt. II, Bd. 15, 1906, p. 435, and Bd. 25, 19, p. 265.
[2] Marchal, Bull. Soc. Roy. de Belgique 45, 1908, p. 343; cited from Centr. Bakt. II, Bd. 34, 1909, p. 563.
[3] Zimmermann, Centralblatt f. Bakt. II, Bd. 7, 1901, p. 141.
[4] Hori. Bull. Jap. Agr. Dept. Vol. I, 1907, p. 153; cited from Jahresb. über Pflanzenkrankheiten, Bd. 10, 1909, p. 144.
[5] Bubak, Zeitschrift fur Pflanzenkrankheiten, Bd. XX, 1910, p. 257.
[6] Loc. cit. Bot. Ztg., p. 24.

Infection experiments were invariably carried out with suspensions of freshly escaped zoospores in distilled water and taken from pure cultures. To maintain the necessary degree of moisture, inoculated plants, seedlings and cuttings (Cereus) were kept under bell jars constantly moist. In most cases checks, *i.e.*, uninoculated plants, were placed under exactly similar conditions as regards moisture.

INOCULATION EXPERIMENTS WITH THE ARECA PHYTOPHTHORA.

1. *Cereus formosus.*—Cuttings were inoculated with suspensions of zoospores as indicated above. Within two or three days a browning of the tissues spreading from the points of inoculation could be made out. This browning gradually passed over into a rot which spread practically through the whole of the inner tissue leaving but a thin skin still firm on the outside. A mycelial web was to be found on the surface which was made up of Phytophthora hyphæ. Sporangia were fairly numerous and along with those formed terminally, were a considerable number of intercalar origin. These were spherical resembling oogonia. In more advanced stages of development a lateral protuberance could be made out, and this on continued observation was seen to grow out slowly into a beak with a hyaline space in it. Through the breaking of the wall at this point, the zoospores were liberated. The process of formation and the emission of the zoospores are illustrated in Plate XVI, Figs. 2–5 (examined eleven days after inoculation). These intercalary sporangia were found only in this case and in one lot of young areca nuts inoculated with a pure culture of the Phytophthora.

Embedded in the tissue and especially in the cells of the epidermis and the layers of parenchyma immediately underlying it were to be found oogonia and antheridia in considerable numbers. In fact it was in this inoculated material that sexual organs were first discovered.

2. Young seedlings of Clarkia elegans, Oenothera biennis, Salpiglossis variabilis and Schizanthus wisetonensis all showed about the same symptoms on inoculation.

The most sensitive seemed to be the Schizanthus which within two days showed most of the leaves discolored and wilted (see Plate IX). After three days all the inoculated plants were badly wilted. Mycelium could be found in abundance in the tissues of leaves and stems. Sporangia were formed on the surface and in the case of Clarkia elegans, oogonia and oospores were to be found, chiefly in the leaf tissues.

3. Very young seedlings of Solanum melongena and Lycopersicum esculentum between one and two inches high and possessing two to four leaves were inoculated as described above. Within four days the plants showed distinct signs of the disease and thereafter gradually wilted down (see Plate X). Examination of the plant showed the typical Phytophthora mycelium in the tissues of leaf and stem and sporangia were to be found on the surface. No oospores were found.

As stated above, larger plants (4–6 inches high) did not show any evidence of disease after inoculation and the same was the case with plants of Solanum tuberosum of about the same size. The results here obtained are in striking contrast to those of de Bary, who states, as quoted above, that all his numerous infection experiments with seedlings of Lycopersicum esculentum were without result. There seems, however, to be some uncertainty as to whether de Bary's statement with regard to the immunity of Lycopersicum esculentum is to be accepted as holding universally. Bancroft[1] in discussing the Cacao Phytophthora states :—"Phytophthora omnivora has also been reported to cause a disease of cultivated tomatoes in England." He does not state his authority and the only reference I have been able to obtain has been kindly furnished by Dr. E. J. Butler, Imperial Mycologist. In the Journal of the Board of Agriculture, March 1910, p. 1012, appears a note on the "Brown Rot of the Tomato" by Bancroft, from which I quote the following :—

"The seeds of infected fruits are of a darker colour than those of healthy ones and a microscopic examination shows that, whereas the testa of the dark-coloured seeds is intact, the tissues of the endosperm and embryo contain fungal hyphæ which from their characters appear to be hyphæ of Phytophthora omnivora."

[1] Bancroft, West Indian Bulletin, Vol. X, 1910, p. 296.

No reference is made to the finding of fructifications of any kind, and I must confess I am unable to understand how Bancroft is able even to guess at the identity of the fungus with P. omnivora from the characters of the hyphæ unless indeed there has been some earlier publication on the subject with which I am not familiar.

Infection experiments with the Cacao Phytophthora on the same plants (with the exception of the larger plants of potato, tomato and brinjal) were made at the same time as the above and the results were practically identical with those already noted (see Plate XI).

The results of these infection experiments show that at least a number of the plants that are susceptible to infection by Phytophthora omnivora may also be infected by the two forms under study. In addition, one plant at least which, according to de Bary, is not susceptible to attack by P. omnivora, has shown itself quite susceptible to attack by our two fungi. The results of my inoculation experiments possess a decided similarity to those noted by Klebahn in his paper cited above. As was the case with Klebahn, I was almost prepared to consider the two fungi under study as identical with P. omnivora after the inoculation results above recorded. He was led, and I think, quite properly, to consider his fungus as a distinct species on the ground of morphological and biological differences which persisted even when the two fungi (P. omnivora and P. Syringæ) were cultivated on the same medium or had infected the same host plant. The chief morphological difference he notes is in the structure of the sporangium. The papilla found at the apex of the sporangium in all other Phytophthoras so far described is lacking in P. Syringæ. I have unfortunately been unable to compare the two fungi under discussion in this paper with material of P. omnivora, something which Klebahn was able to do. The account given by Klebahn of the growth of Phytophthora omnivora on artificial media (agar, carrot, potatoes, etc.) shows some differences in cultural characters as compared with the Areca Phytophthora, chief of which is the formation of oospores, something which I have never observed although a great many such cultures have been examined.

In addition to this, differences in the morphology, especially in the size of the oospores and in the case of

the Cacao Phytophthora in the apparent suppression of the antheridia, would seem to justify us in distinguishing the Cacao Phytophthora, at least, as a distinct species.

As to the inter-relationships of the two forms, cross inoculation experiments have been carried out to attempt to settle the question whether we have really to do with one and the same fungus. These experiments have not been quite conclusive, owing largely to the fact that they had to be conducted at a time of the year when conditions were not particularly favorable. Three small Cacao pods kindly furnished by Mr. H. E. Houghton, Superintendent of the Madras Botanical Gardens, were inoculated with zoospore-suspensions from pure cultures of the Areca Phytophthora. Of these, one remained quite unaffected, one, the smallest, showed the signs of typical brown rot and on microscopic examination revealed Phytophthora mycelium in the tissues but no sporangia on the surface and no formation of oospores. The third also became decayed, but, apparently, as a result of some slight injury and saprophytic attack, as a microscopic examination revealed no sign of Phytophthora either on the surface or in the tissues.

On the other hand, inoculations of areca nuts from pure cultures of the Cacao Phytophthora were not more successful. Altogether some hundred nuts were inoculated at various times and invariably with negative results with the exception of one single dish of six nuts about one month old which showed an unmistakable infection. Check inoculations with the Areca Phytophthora carried out at the same time invariably gave an amount of infection which varied considerably but was always quite convincing. It is proposed during this year's monsoon to repeat these cross inoculations with fresh material of both fungi.

In a discussion of the relationships of these two fungi to each other and to P. omnivora there are several points to be noted and it will be well to consider the two forms separately.

The Areca Phytophthora has undoubtedly a very strong resemblance to the European form. The sporangiophores appear to be identical with those of P. omnivora in their mode of development and their degree of complexity in water cultures. The sporangia which vary

greatly in size and shape in both forms fall within about the same limits in each. The one difference worthy of notice is the occasional formation of intercalary sporangia in the Areca Phytophthora as already described. The mode of attack seems to be identical in the two forms, any slight difference which may occur such as penetration through stomata in the one case and through or between epidermal cells in the other, being probably attributable to differences in the hosts rather than in the fungi themselves. The structure of the haustoria would, at first, seem to yield a point of difference. Hartig describes and figures them for Phytophthora omnivora as spherical, while de Bary gives no definite information about them, simply stating that they occur but rarely. Klebahn, however, in his recent paper, describes and figures them as rather elongate and finger-like, in which case they agree closely with those of the Areca Phytophthora. The only important morphological point of difference appears to be the size of the oospores. According to the measurements given by de Bary the oospores of Phytophthora omnivora are markedly smaller than those of the Areca Phytophthora. Klebahn gives no measurements for the omnivora material examined by him, so we must presume that in this respect his results agreed with those obtained by de Bary.

As to the behaviour of the two fungi in artificial media there seem to be some points of difference. Klebahn found that Phytophthora omnivora formed both sporangia and oospores on plum agar and apparently also on sterilised carrots and potatoes. In none of my cultures of the areca fungus on malt agar and potatoes did I find any trace of sexual organs, and a sparse formation of sporangia was observed in but one culture and that on malt agar. In all my other cultures numbering some twenty or thirty the fungus remained quite sterile. On sterilised flies in water sporangia were formed in abundance, but there were no traces of sexual organs, while on aseptically taken areca nuts in Roux-tubes sexual organs were found in numbers while sporangia were very rare. This last was cleary due, at least in part, to the lack of water, for on areca nut slices immersed in water only sporangia and no sexual organs were found.

The areca fungus has been found capable of infecting

a number of plants susceptible to attack by Phytophthora omnivora, and at least one species (Lycopersicum esculentum) which according to de Bary is quite immune. Bancroft's note hardly brings de Bary's conclusions into question.

In this connection it is worthy of note that Klebahn, following on the positive results obtained by him with P. Syringæ in inoculations on host plants of P. omnivora, notably on seedlings of Fagus, has suggested the possibility that, under P. omnivora, we have really to do with a number of different fungi. As is well known, de Bary brought under this name Phytophthora (Peronospora) cactorum, Lebert and Cohn, P. Sempervivi, Schenck, and P. Fagi, Hartig. Klebahn rightly points out that the descriptions given by the different authors show by no means a complete identity of structure on the different host plants. Cross inoculations of a form found on one host plant on to the host plant of another form did not invariably give results identical with those produced by the fungus actually found in nature on this second host.

The following may serve as examples of this discrepancy :—De Bary[1] attempted infection of cacti (Cereus speciosissimus and Cereus peruvianus) with the fungus found by him on Cleome violacea, Schizanthus pinnatus, etc., but got by no means the same severity of attack as Lebert and Cohn did with P. cactorum on Cereus giganteus and Melocactus nigrotomentosus. He succeeded in producing only a very slight infection with the formation of a few sporangia and no sexual organs. The diseased areas were soon cut off from the healthy tissue by cork-formation. He considered the difference in results to be due to differences in the host plants, as the morphological characters of the two fungi appeared to be identical. Osterwalder,[2] in his investigation of a Phytophthora rot of apples, carried out cross inoculations on beech-seedlings and on plants of Sempervivum tectorum. Inoculations were made in artificial wounds on the cotyledons and leaves. They were, however, only partially successful. In neither case were the plants killed, and from the account given the disease does not seem to have spread from the inoculated leaves. Both sporangia and oospores

[1] Loc. cit. Bot. Ztg. 1881.
[2] Loc. cit.

were, however, formed in the infected organs. From these results as well as from the morphological resemblance Osterwalder concluded that his fungus was identical with Phytophthora omnivora. His method of inoculation seems to me to be open to question, and one would hardly need to premise a strong parasitism on the part of the fungus to account for the results obtained by him.

From the above considerations it would appear that a careful revision of the species P. omnivora is needed and this seems particularly necessary for those fungi found outside of Europe which have been identified as this species. It would appear, also, that other Phytophthora species are in need of revision. As an example, Jensen[1] suggests the possibility that P. Nicotianae, Breda de Haan may be identical with P. infestans. Somewhat similar doubts have been expressed by Clinton[2] with regard to P. Thalictri.

Finally, in considering the relationships of the areca fungus it must not be forgotten that, as far as at present known, it occurs in India only as a parasite of the areca palm and that in a rather inaccessible part of the country where the likelihood of its having been introduced from Europe seems very slight indeed. Moreover, in the more northerly affected tract it appears to have been present for a very long time, probably for hundreds of years. There is, in fact, a legend among the garden owners that the disease caused by it was sent as a curse by Rama.

Whether we should consider this fungus as a distinct and new species seems, on the whole, rather doubtful. Although there are some grounds for doing so, I should prefer for the present to place it with P. omnivora but as a distinct variety until such time as I shall have been able to make a thorough search for alternate host plants and until the different *omnivora* forms have been carefully investigated. It seems advisable to name and describe the areca fungus provisionally as follows:—

Phytophthora omnivora, var. Arecae. Differs from the type in having large oospores, diameter 23μ–36μ. Sporangia usually as in P. omnivora but occasionally formed intercalarly. Oospores not formed in artificial

[1] Jensen, Jaarboek van het Departement van Landbouw in Nederlandsch Indië, 1906, p. 367.
[2] Clinton, loc. cit., 1907-08, p. 895.

cultures on malt agar and potato, rarely if at all in nature on the host plant abundant on areca nuts in pure culture and on Cereus and Clarkia elegans. Mycelium inter- and intracellular, septate only in older stages. Haustoria sparse, finger-like, occasionally dichotomously branched. Habitat in bases of leaves, fruits, peduncles, and apex of areca catechu. Distribution—Western Mysore, North Canara, South Canara, Southern Malabar and Cochin.

If we now come to the second fungus under investigation, that found upon fruits of Cacao, we find greater morphological differences. It is true that some of the distinguishing characters noted by von Faber[1] do not hold. The sporangiophores produced in water cultures are variable but may under favourable conditions reach a complexity quite as great as that described by de Bary for P. omnivora. I have not counted the zoospores emitted by a single sporangium in this fungus, but counts made on the Areca Phytophthora gave a number varying from 10 to over 40, which agrees with de Bary's description of P. omnivora. As the sporangia and zoospores of the areca and Cacao forms are similar in size, there is no reason to suppose that counts made on the latter fungus would not give similar results. Von Faber himself admits that in his culture a normal development and emission of zoospores may not have taken place.

The mycelium and the asexual reproductive organs of the Cacao fungus resemble those of P. omnivora strongly. The sexual organs and products are, on the other hand, decidedly different. Not only are the oogonia and oospores decidedly larger than those of P. omnivora, but, what seems to me much more important, there is also a well-marked parthenogenesis which in my experience persists in all artificial cultures and on all alternate host plants where sexual organs are formed. The oospore, instead of filling the oogonium only two-thirds to four-fifths as described by de Bary, occupies practically the whole of the oogonial cavity, so that it is usually difficult to distinguish the oogonial wall surrounding it. Antheridia appear to be entirely absent and are certainly not usually formed. I have not seen any sign of them in the many preparations examined. Oogonia and oospores are formed

[1] Loc. cit.

in those artificial cultures (on malt agar and sterilised potato) in which the fungus thrives. This appears to be also the case with P. omnivora, but, as noted, is not the case with the areca fungus. Finally, the fungus is capable of infecting a number of the host plants of P. omnivora and also seedlings of Lycopersicum esculentum. Infection of areca nuts is produced with difficulty.

From the above it appears clear that this fungus, although closely allied to P. omnivora and the areca fungus, is still a distinct species, and I propose for it the name Phytophthora Theobromæ as indicating its typical host plant.

Phytophthora Theobromæ, sp. nov. Mycelium richly branched both inter- and intracellular, unseptate in the earlier stages of growth, but later forming septa which frequently serve to separate off empty and dead portions of the mycelium. Haustoria not observed. Sporangia generally ovate but somewhat variable in shape. Extreme measurements as given by von Faber are $25 \times 30\mu$ and $42 \times 80\mu$. Sporangiophores in water cultures sympodially branched as in P. omnivora and bearing up to 20 sporangia or more. Oogonia formed intra-matrically in the host plant as well as in artificial cultures on agar and sterilised potato. Antheridia absent or if at all present only rarely formed. Oospores entirely or for the most part formed parthenogenetically, practically filling the oogonial cavity, in artificial cultures spherical, in the host tissue spherical, elongate or irregular, 22μ to 45μ in diameter. Found as a parasite on fruits of Theobroma Cacao, and also upon fruits of Hevea brasiliensis and Artcarpus incisa according to Petch. Found capable of infecting a number of the host plants of P. omnivora and in addition seedlings of Lycopersicum esculentum.

According to Busse (loc. cit.) this fungus also attacks the bark of Cacao trees.

Since the above was written an article by Petch in the "Tropical Agriculturist" has brought to my notice the fact that the Cacao fungus has already been given the

name of Phytophthora Faberi. Mr. Petch has kindly furnished me with the reference to the article containing the description. Maublanc, who has continued Delacroix's articles on "Les Maladies des Plantes Cultivés dans les Pays Chauds" in "L'Agriculture Pratique des Pay Chauds," has, apparently without any examination of the fungus, erected a new species on von Faber's description. The following is the description kindly furnished me by Mr. Petch from "L'Agriculture Pratique des Pays Chauds," No. 79, 1909, p. 315 :—

"Phytophthora Faberi, nov. sp. Taches irrégulières, brunes ; spores blanc ou jaunâtre peu visible; conidiophores longs de 150μ à 200μ, continus, hyalines et terminés par une condidie apicale, plus rarement, rameux et portant 2 conidies ; conidies (sporanges) de forme variée généralement en citron, à membrane mince, lisse, un peu épaissie au sommet 30–80μ = 25–41μ, oospores arrondies lisses à membrane épaisse, 45μ de diamètre.

"Parasite sur les fruits du Cacaoyer, dans les régions Chauds.

"Distinct du P. cactorum (Cohn et Leb.) Schr. par la dimension des oospores et le moins grand nombre des zoospores produites à la germination des conidies."

It will be seen on a comparison with von Faber's paper that Maublanc adheres almost exactly to his description. Although von Faber did not feel justified in erecting a new species on the data he had collected, that in no way deters Maublanc. As to the designation, it is naturally immaterial which of the two names should be given to the fungus, although it seems to me a somewhat unusual and questionable thing to do, to establish a new species on another author's description especially when that author expresses himself with such exemplary caution as von Faber has done in his paper. A comparison of his description with that given above reveals considerable differences. In fact Maublanc falls into errors common to those who attempt to build entirely on other investigators' work without making a critical examination of the facts themselves.

EXPLANATION OF PLATES V—XVIII.

All drawings were made with the Abbe camera lucida and Zeiss apochromatic lenses. In all cases where not otherwise stated drawings were made from fresh or alcohol material which in the case of sections was usually cleared with lactic acid and stained with lactic acid cotton blue. This latter is an excellent stain for use in distinguishing fungus mycelium in plant tissues.

PLATE V.

FIG. 1.—Areca nuts artificially inoculated by means of a suspension of zoospores of the Areca Phytophthora in water. The inked ring marking the space upon which the inoculating drop was placed is still visible. From a photograph about two-thirds natural size.

FIG. 2.—Microphotograph of a longitudinal section of a diseased nut-shell fixed in Flemming's fluid and stained with Heidenhain's Iron Haematoxylin. The surface of the epidermis lies along the line between A-A. Above this is the mycelial felt with sporangia embedded in it. About the middle of the figure the fungus hyphæ are seen breaking through the epidermis on to the surface. Magnified about 100 times.

FIG. 3.—Microphotograph of part of a culture of the Areca Phytophthora in water showing the sporangia. Magnified about 200 times; from live material.

PLATE VI.

Photograph of the top of an areca palm attacked by the Areca Phytophthora. The bunches are quite dead and the leaves have begun to wither.

PLATE VII.

Photograph of the top of a diseased areca palm split longitudinally. The bunch stalks are quite destroyed and the blackish line in the tissue of the stem about the origin of the bunch indicates the presence of the disease.

PLATE VIII.

Photograph of top of a diseased areca palm split longitudinally. The bunch stalk at its point of attachment appears quite healthy, whereas the growing-point and the bases of the leaf-sheaths are quite decayed.

PLATE IX.

Photographs of a portion of a garden at Chowdikodlu near Talaguppe. Near the centre of each figure is a climber with sprayer in operation. A number of the trees show *kottes* on their bunches.

PLATE X.

FIG. 1.—Seedlings of Oenothera biennis. Those in the pot to the right were inoculated from pure cultures of the Areca Phytophthora as described in the text. Those in the pot to the left were kept uninoculated as checks. Photo 25th September 1909, three days after inoculation.

FIG. 2.—Seedlings of Brinjal (Solanum melongena). Check plants in pot to the right. Inoculated plants in pot to the left. Photo 6th October 1909, four days after inoculation.

In both figures the surface of the soil in the pots has been sprinkled with white glass-sand to give better contrast.

PLATE XI.

FIG. 1.—Seedlings of Schizanthus wisetonensis. Those in the two pots above were inoculated with material from pure culture of Cacao Phytophthora. Those in the two pots below were kept as checks. Photo 25th October 1909, two days after inoculation.

FIG. 2.—Seedlings of Tomato. Pot to the right contains plants inoculated from pure culture of the Cacao Phytophthora. Pot to the left contains check plants. Photo 6th October 1909, four days after inoculation.

PLATE XII.

FIG. 1.—Surface view of a small part of areca nut shell showing the Areca Phytophthora in process of coming out through a stoma and of forming sporangia. ×425.

FIG. 2.—Hyphæ of the fungus bursting outer wall of epidermal cell. ×850.

FIG. 3.—Tuft of fully-formed sporangia sessile on surface of nut-shell. ×350.

FIG. 4.—Hyphæ of fungus making exit through burst outer wall of epidermal cell of nut-shell. ×850.

FIG. 5.—Longitudinal section of a shell of areca nut showing hyphæ breaking forth and forming sporangia. Epidermal cells crowded with mycelium. ×850.

PLATE XIII.

FIG. 1.—Surface view of areca nut shell showing fungus hyphæ breaking forth. Rudiments of sporangia have been formed in four cases but later vegetative growth has taken place from their distal ends. ×850.

FIG. 2.—Surface of nut-shell showing hyphæ coming out through stoma and growing out vegetatively without formation of sporangia. ×850.

PLATE XIV.

FIGS. 1-3.—Sections of shell of areca nut showing intercellular mycelium of the Areca Phytophthora with finger-like haustoria. ×850.

FIG. 4.—Section of areca nut shell showing a hypha of the fungus growing through cells of the parenchyma. ×850.

FIGS. 5-6.—Sections of the parenchyma of a leaf-sheath which has been inoculated with the Areca Phytophthora, showing hyphæ inter and intracellular. ×850.

PLATE XV.

FIG. 1.—Series of drawings of developing sporangium from a water culture showing its growth and differentiation. In the last three drawings of the series the formation of a second sporangium is shown. ×350.

FIG. 2.—Sporangia of the Areca Phytophthora from the surface of the diseased nut. They were all drawn to the same scale to show the great variability in their size and shape. ×425.

FIG. 3. Sporangiophore of the Areca Phytophthora from water culture showing system of branching. × about 100.

FIG. 4.—Transverse section of part of vascular bundle from an areca leaf-sheath showing fungus hyphæ in a vessel. ×850.

PLATE XVI.

FIG. 1.—Sporangium fixed in osmic acid to show the demarcation of the zoospores previous to their emission. ×775.

FIGS. 2–5.—Intercalary sporangia of the Areca Phytophthora grown on cutting of Cereus. Fig. 4 shows emission of zoospores. Fig. 5 shows empty sporangium after all zoospores have escaped. ×850.

FIG. 6.—Germinating zoospores. ×750.

FIG. 7.—Germinating zoospores infecting areca nut, their germ tubes entering a stoma. ×850.

PLATE XVII.

FIGS. —1–3.Stages in the development of the sexual organs and formation of oospore. In Fig. 1 a central vacuole is to be seen in the oogonium. In Fig. 2 the oogonial mass (ooplasm) has contracted from the wall and the vacuole has disappeared. In Fig. 3 fertilization tube of the antheridium is to be seen.

FIGS. 4–7.—Stages in the development of a second pair of sexual organs to show especially the amœboid contraction of the ooplasm.

FIGS. 8–9.—Completion of the formation of an oospore. In Fig. 8 fertilization appears to be complete. In Fig. 9 the penetration tube of the antheridium has disappeared and the antheridium itself appears to be empty. Figs. 1-9 all magnified. ×670.

FIG. 10.—Terminal branches of mycelium of Areca Phytophthora from culture on malt agar. ×425.

PLATE XVIII.

FIGS. 1–3.—Mature oospores of Areca Phytophthora from mycelial felt on surface of areca nut. The drawings were made about seven months after the formation of the oospores from hanging drop cultures and are particularly to illustrate the persistance of the oogonial and antheridial walls. ×850.

FIGS. 4–9.—Oospores of the Cacao Phytophthora from culture on malt agar. Figs. 4-6 show presence of oogonial wall for the most part closely applied to that of the oospores. In no case is there any sign of antheridium. ×850.

FIGS. 10–13.—Oogonia (oospores?) of the Cacao Phytophthora embedded in the parenchyma of a diseased Cacao pod. ×850.

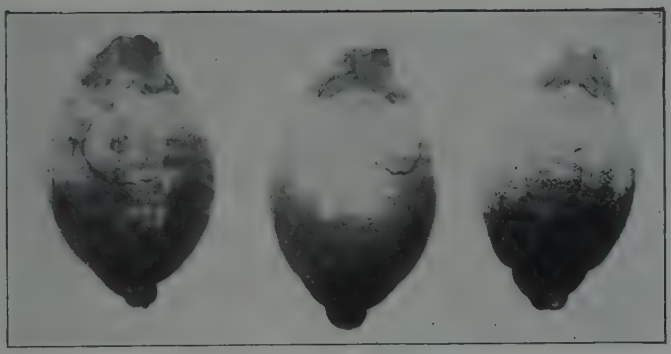

Fig. 1.

A

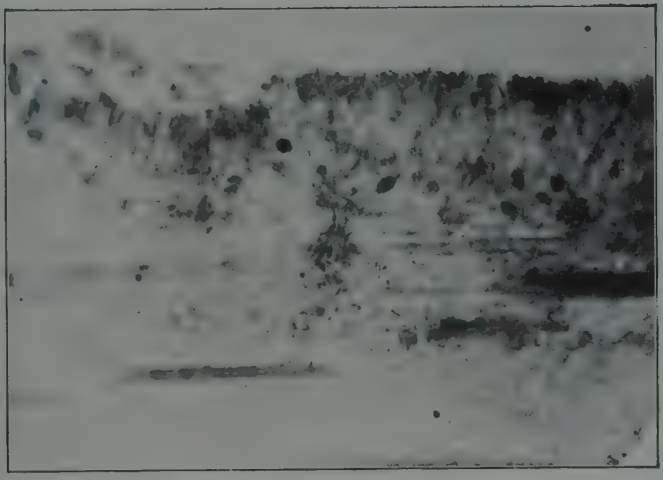

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Fig. 2.

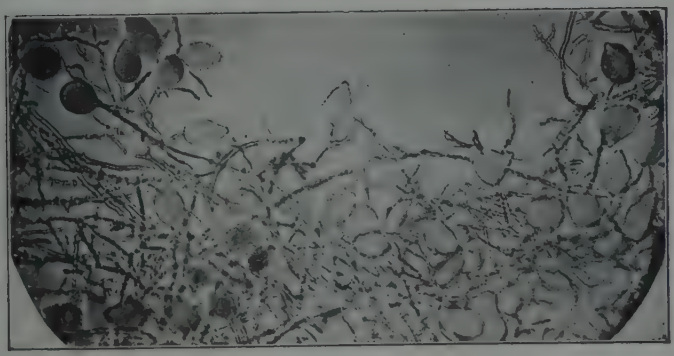
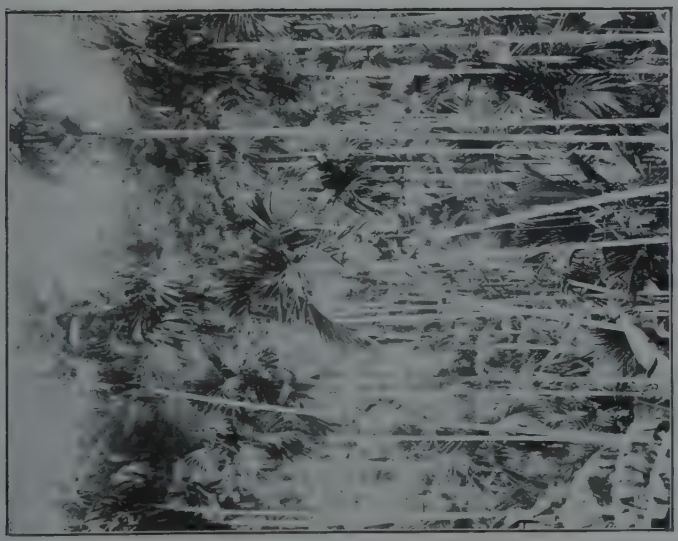


Fig. 3.

Plate VI.

Plate VII.

Plate VIII.



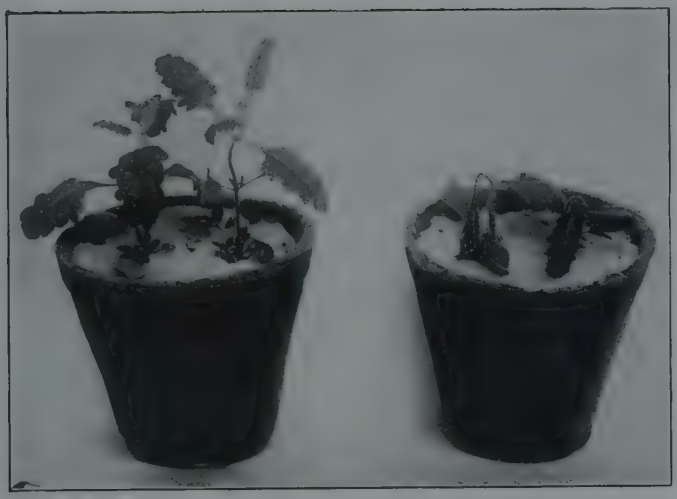


Fig. 1.

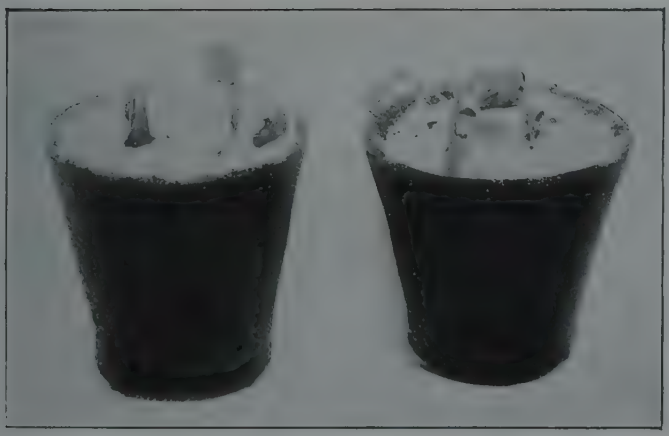


Fig. 2.

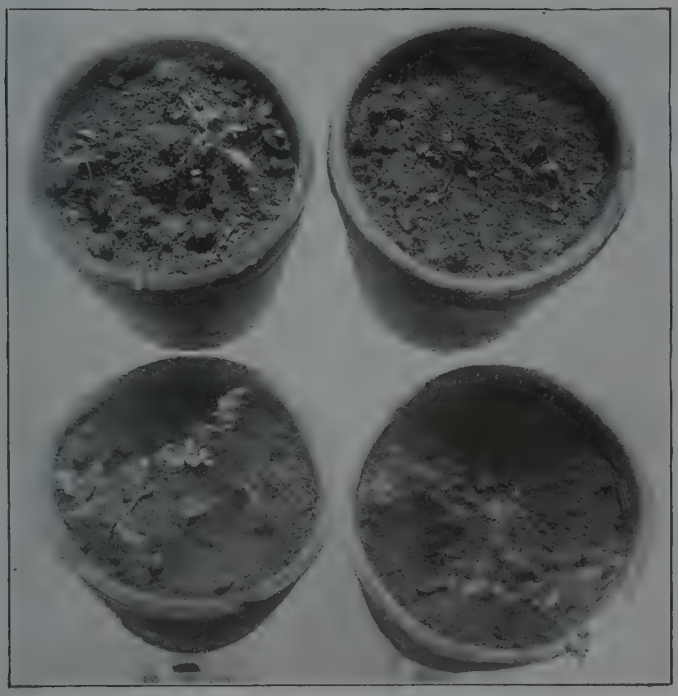


Fig. 1.

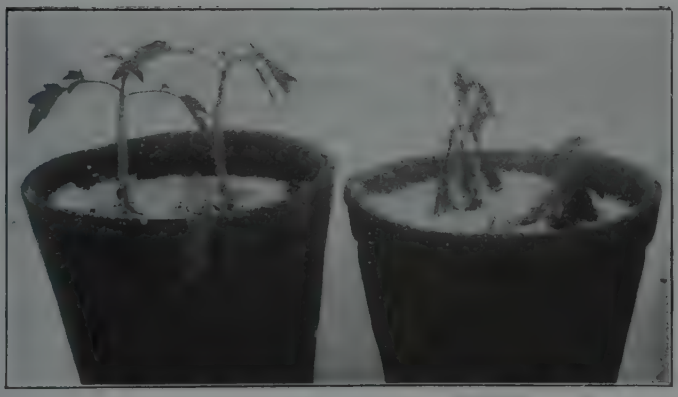


Fig. 2.

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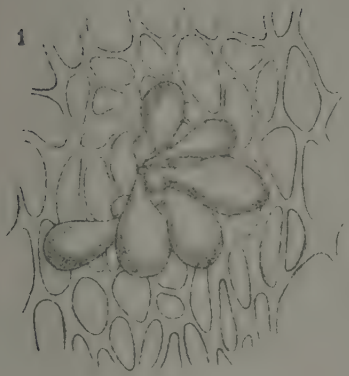

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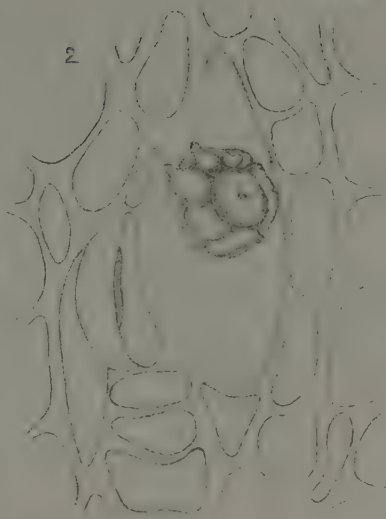

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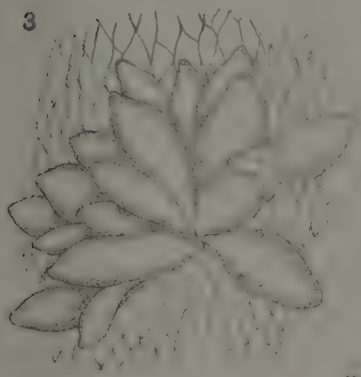

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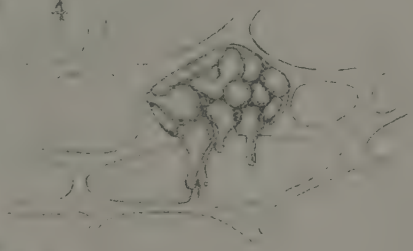

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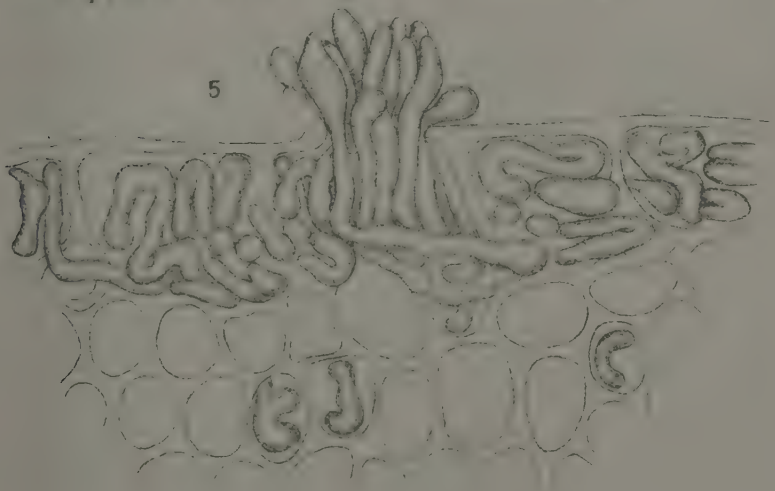

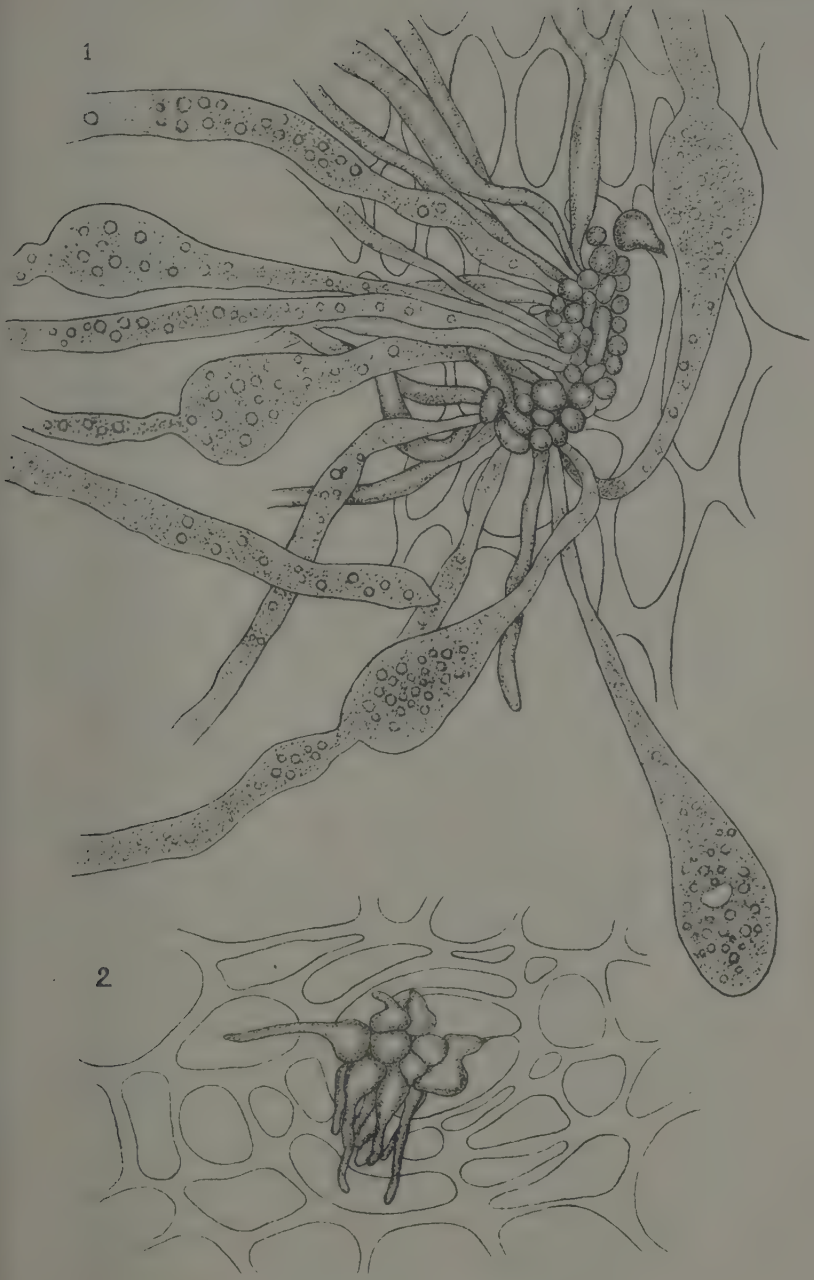
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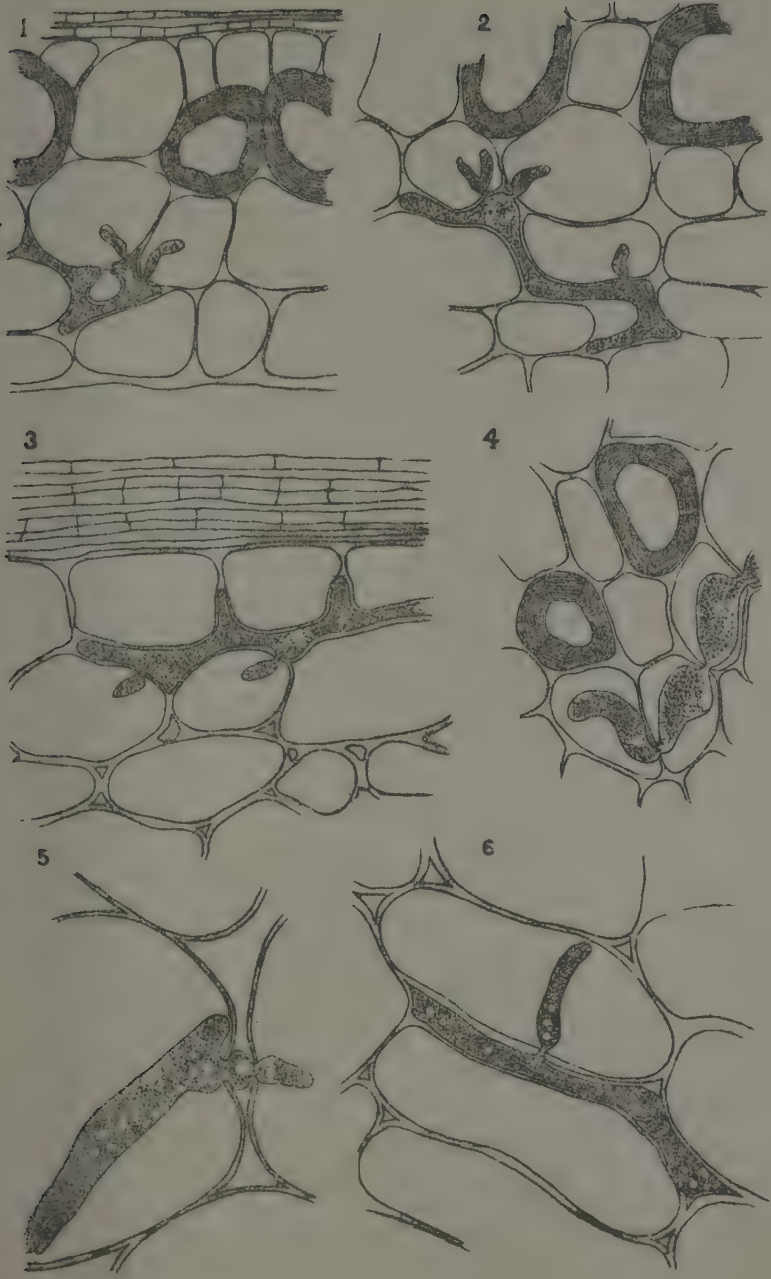
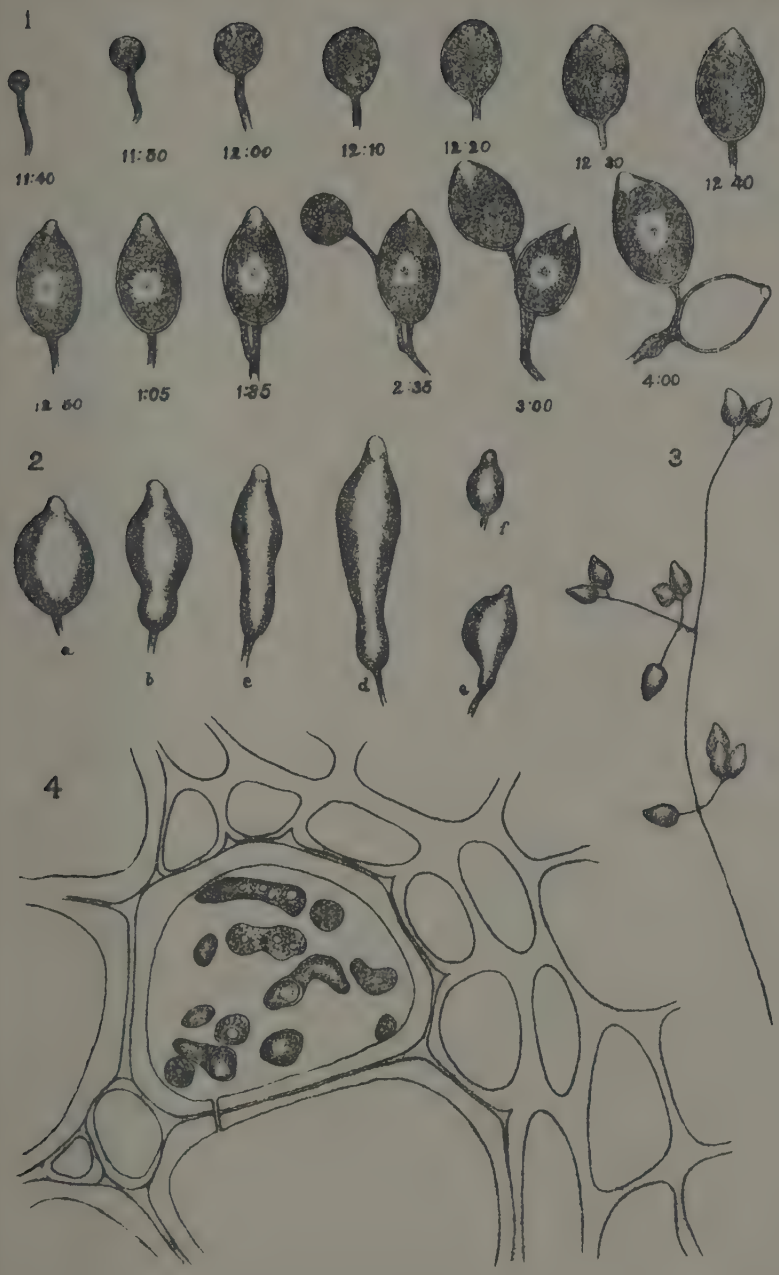
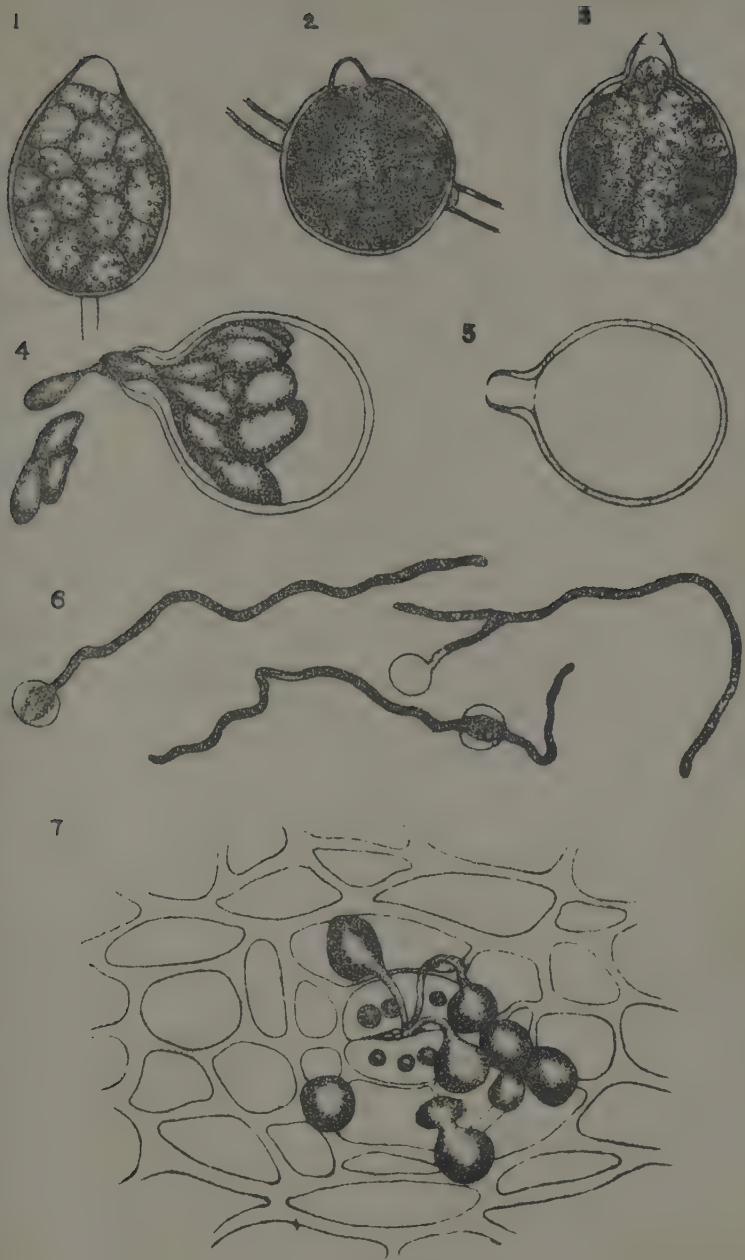
2

Plate XIV




1
11:40
11:50
12:00
12:10
12:20
12:30
12:40
12:50
1:05
1:35
2:35
3:00
4:00
2
a
b
c
d
e
f
3
4


1
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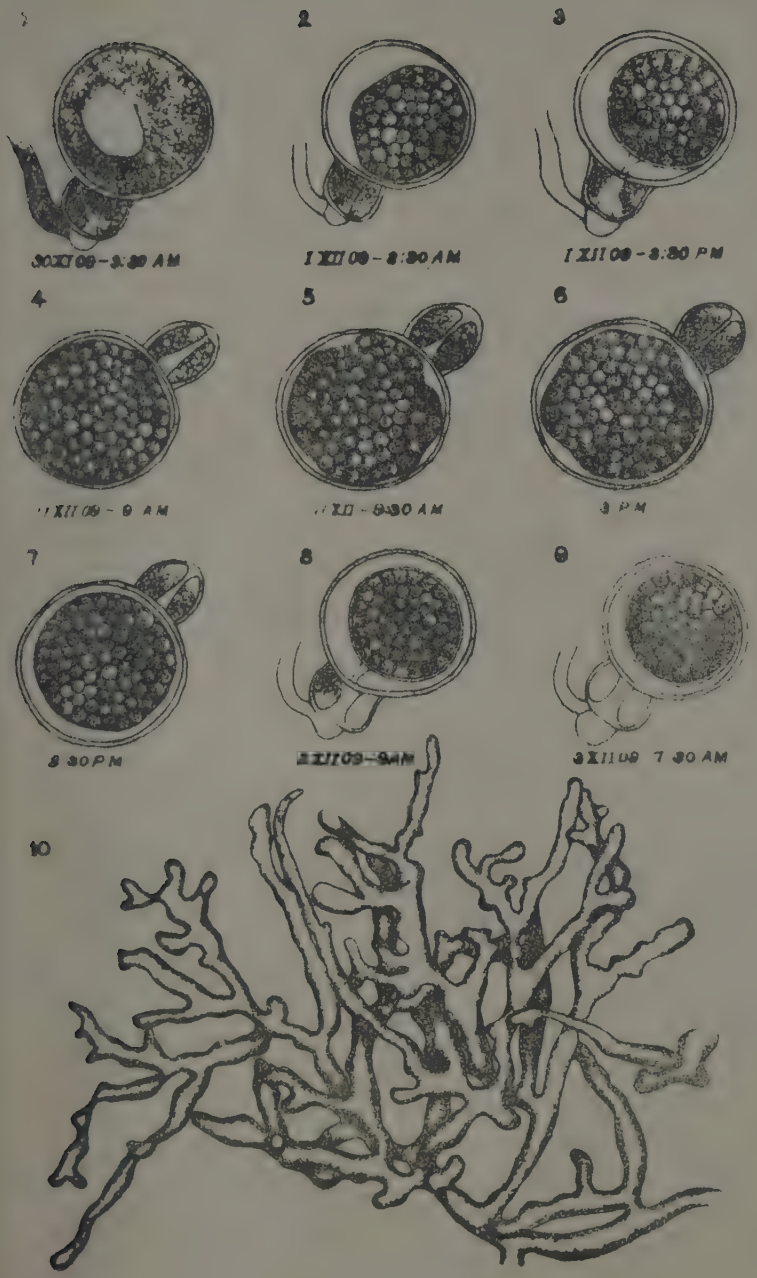
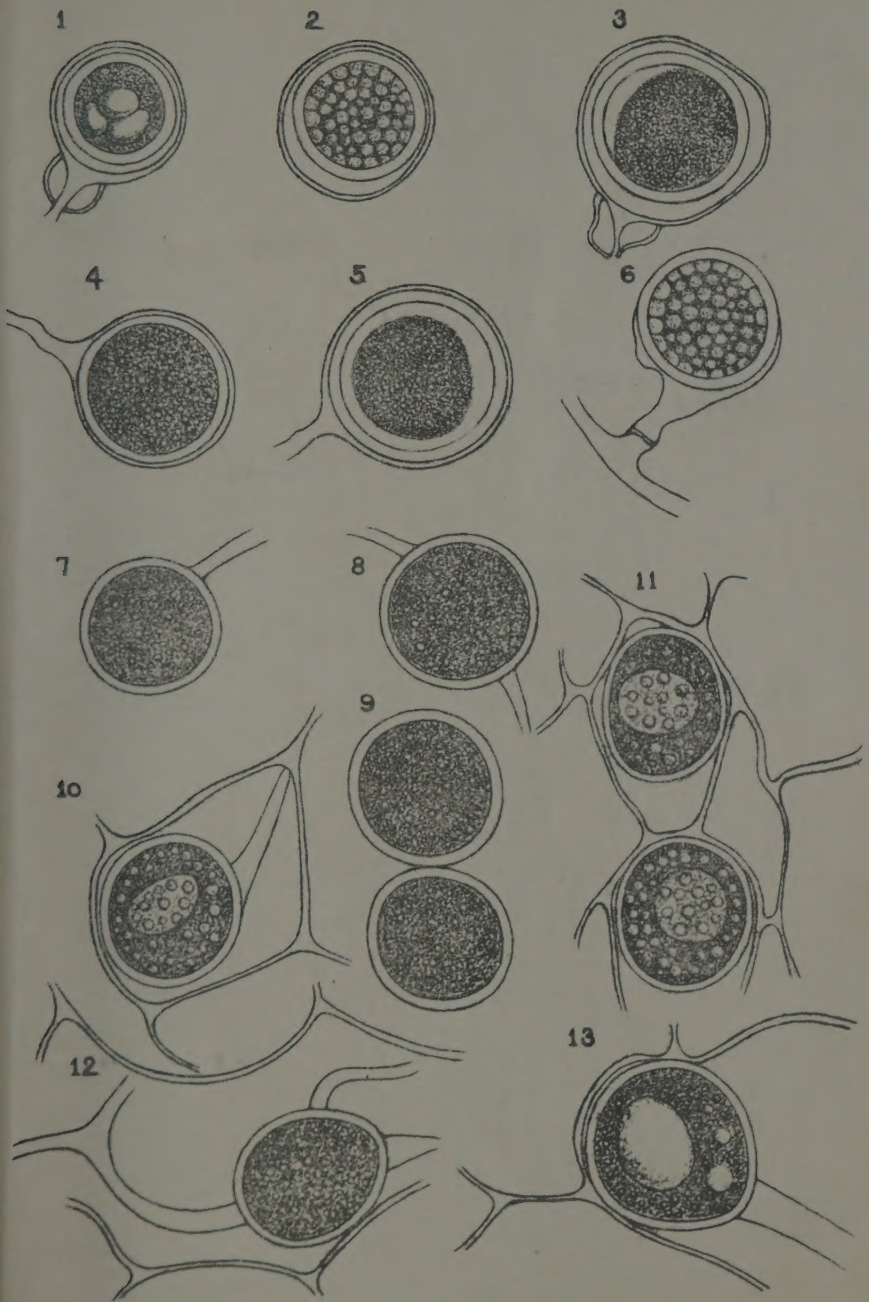
7

Plate XVII


1
30XI'09 - 8:30 AM
2
I XII'09 - 8:30 AM
3
I XII'09 - 8:30 PM
4
XII'09 - 9 AM
5
XII - 8:30 AM
6
3 PM
7
8 30 PM
8
9
3 XII'09 7 30 AM
10


1
2
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